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ESTABLISHMENT OF A CUTTING FLUID CONTROL SYSTEM (PHASE I)

By

G.A. Lieberman

JANUARY 1981

U.S. ARMY

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TECHNICAL REPORT

TRW, INC.

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Phase I results are presented for the program entitled "Establishment of a Cutting Fluid Control System". The Phase I objectives were to analyze existing Rock Island Arsenal manufacturing processes and requirements, conduct systematic evaluations of available fluid products, and develop a preliminary fluid selection and application matrix. The study showed the majority of observed machining operations involve milling, turning, grinding, and boring procedures on 4100 series steels. A severity index was developed which ranked all these processes relative to machining difficulty with respect to cutting parameters,

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tool design, workpiece hardness, and specific machining process. Commercially available cutting fluids were also ranked according to composition and manufacturer's recommendations. A total of sixty-five fluids were subjected initially to screening tests involving residue, rust, and bacterial growth with selected fluids then employed in cutting tests. The latter tests employed specially instrumented machine tools which provided force, power consumption, and tool wear data.

Results are presented which indicate fluid performance levels are not necessarily related strictly to overall product formulations and that milling and turning require significantly different fluid properties. Data are also presented which suggests that only a very limited number of fluid types may be required for plant-wide application at Rock Island Arsenal. Methodologies are defined for establishing a quantitative index describing the relative severity of any given metal removal operation in relation to the fluid properties required for optimum performance on the machine. Initial recommendations are also presented outlining the design features for a closed-loop fluid reprocessing system.

FOREWORD

This report was prepared by Mr. G. A. Lieberman, Machining Technology, TRW, Inc., Cleveland, OH, in compliance with Contract No. DAAA08-80-C-0033. The principal co-investigator was T. S. Stelson, Engineer, with Program Management provided by Dr. C. F. Barth, Section Manager, Machining Technology Section of Materials Development, and I. J. Toth, Department Manager. Technical support was provided by J. M. Gorse and R. A. Whittington. The TRW internal Report No. ER-8121-F has been assigned for this report.

The work was under the direction of the Engineering Directorate, Rock Island Arsenal, Rock Island, IL, with Mr. R. E. Johnson as Project Engineer.

This project was authorized as part of the Manufacturing Methods and Technology Program and was administered by the US Army Industrial Base Engineering Activity.

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1.0 INTRODUCTION

Current manufacturing facilities involve complex combinations of processes utilizing varieties of technologies spanning many engineering and scientific disciplines. They involve considerations in areas such as: finished part requirements, material application, tool design, equipment design, quality control, material handling human factors, environmental control and government regulations. Many advancements have been made in these areas. Tooling, for example, has made great advances in the last eighty years. The time required to turn a straight cylinder four inches in diameter and twenty inches in length has decreased considerably according to data developed by Sandvik Incorporated. During the early 1900's, carbon-steel tooling would require 100 minutes to complete this job. High speed steel tooling reduced this to 26 minutes. Stellite tools which were introduced just prior to World War I further decrease the machining time to 15 minutes. This machining rate was cut in half to 6 minutes by the introduction of cemented tungsten carbide. Premium carbide, introduced in the 1950's, further reduced this rate to 3 minutes. The time was again halved to 1.5 minutes with the advent of the first coated carbides. Current advances have reduced the initial 100 minute machining time to 1 minute using aluminum-oxide coated inserts.

Similar advances have been made in machining equipment. Numerical control (N/C) machines have reduced some of the machine operator skill requirements in manufacturing, as well as reducing the costs to produce small quantities of production parts. N/C computer control now coupled with computer-aided design is reducing the time required to develop N/C programs. Also, these computer-aided N/C machines equipped with multiple cutting axis capabilities make it possible to manufacture highly complex space age parts. Likewise, systematic work has been done at the universities and industrial research laboratories in the area of advanced tooling geometries. Designs for maximum productivity and less obvious factors such as chip control have been developed.

However, one major area having a great impact on the productivity and costs incurred in these operations has been neglected from an application point of view. Studies have shown that the correct selection and use of cutting fluids within a manufacturing facility can provide enormous benefits in part quality and reduced cutting tool consumption. While the cutting fluid manufacturers and distributors have concentrated efforts in developing new formulations and fluid types based upon chemistry principles, most lack the capability of actual production floor testing of these new products. This creates problems for the end users who are faced with literally hundreds of fluids from which to choose for their manufacturing facility. Many times the final cutting fluid selection is based upon a single person's judgement which reflects his past experience and recent input from the various vendors. An alternate evaluation mechanism, with adequate, scientifically established data as a basis, will permit management personnel to select the proper fluid(s) for their specific applications. Another aspect to this problem is the proper maintenance and use of the optimum cutting fluids selected. These two factors have perhaps the greatest effect upon the benefits to be gained by proper fluid selection.

It was with these thoughts in mind that a program was formulated to provide implementation of advanced cutting fluid technology into the manufacturing operations at Rock Island Arsenal (RIA). The overall goal of this program is to establish a cutting fluid selection and control system, based upon performance data, which will improve productivity and reduce manufacturing costs at RIA. The program is comprised of three distinct phases, each with specific objectives. Phase I will be devoted to the development of a systematic quantitative procedure to evaluate various cutting fluids as related to the manufacturing requirements at RIA. Included in this effort were the following: develop a manufacturing severity index, characterize potential fluid chemistries in cooperation with fluid manufacturers, develop and conduct a test plan which will be used to select optimal fluid compositions for an application matrix, define process economics and develop a preliminary fluid application matrix. The second phase of the program will involve further refinements of the fluid application matrix and the severity index. The objective of the third phase will include the development of a plant-wide cutting fluid control system.

This report describes the work accomplished in Phase I of this program.

2.0 BACKGROUND AND TECHNICAL APPROACH

This section is intended to provide background technology relative to cutting fluids in metal removal operations and outline the technical approach employed for this program.

2.1 Background Technology

TRW Materials Technology has been actively conducting research in the metal removal area for the past decade. The work has addressed both fundamental and applied research problems. One of the primary objectives of this research has been to perform highly controlled and systematic investigations of metal removal processes to develop a comprehensive knowledge base such that technology would be transferred to the shop floor. Without consideration of the necessity for process implementation, most experimental results would remain only of academic interest.

A naturaldevelopment of the systematic study of metal removal phenomena at TRW was evaluation of the role played by cutting fluids. One of the first revelations was that cutting fluid technology has been largely ignored relative to efforts within the industry to develop, for example, NC control systems and improved cutting tool materials. TRW has conducted extensive studies specifically designed to define requirements for cutting fluids in both grinding and metal cutting operations. Possibly the most significant finding arising from this work has been that fluid composition was consistently one of the most important factors governing overall process economics and productivity regardless of the manufacturing process analyzed.

2.1.1 Cutting Fluid Technology

An overview of the function of cutting fluids as determined by TRW investigations will be presented prior to discussions of specific examples of successful technology implementation. A cutting fluid provides four major functions in metal removal operations; heat removal, lubrication, chip flushing, and to varying degrees, alteration of the mechanical properties of the chip during its generation. Selection of the proper fluid demands providing the proper combination of these factors to satisfy particular application requirements.

Cutting velocity exerts a strong influence on the selection process. In general, slow cutting speeds require more lubrication while at higher speeds heat abstraction, chip flushing, and mechanical property changes are more critical. Lubrication at the tool-chip interface occurs by two basic mechanisms. The first involves conventional elastohydrodynamic (EHD) films where no surface contact occurs and the load is totally supported by the fluid film. The second mode, more common in metal cutting, is boundary film lubrication where some metal-to-metal contact occurs between surface asperities and pockets of lubricant are trapped between these contact areas. This latter type of lubrication is observed when straight oils or water/oil emulsions are utilized in metal removal. A third type of lubrication is possible when special additives are present in the fluid which chemically react to form adherent layers of solid film materials on the opposing surfaces to physically separate the interfaces. Additions of sulfur, chlorine and phosphorous compounds, and fatty acids cause formation of low shear strength films that prevent or reduce welding of contacting areas and minimize both material transfer and generation of metallic debris within the contact zone. Moisture and dissolved oxygen in the cutting fluids also contribute to film formation and may chemically modify the films formed by the intentionally added compounds. An illustration of the three lubrication modes is presented in Figure 2.1-1. Boundary lubrication with solid films is the prevailing condition in most metal removal operations.

The critical factors in achieving satisfactory boundary lubrication with film formation are the chemical activities of the additives in the fluid, the activity of the tool/workpiece materials, and the time-temperature-pressure (TTP) conditions existing as a chip passes across the tool. For a given set of cutting conditions, a dynamic TTP situation prevails with increasing temperature and pressure levels occurring as the tool wears. This TTP factor can be considered useful in developing a process severity index for appropriate fluid selection.

Selection of the optimum cutting fluid composition must then seek to provide adequate cooling while providing sufficient activity in the additive package to develop a chemical film which is just thick enough to prevent direct asperity contact during the time interval of chip/tool interaction. Inadequate film thicknesses permit direct metallic contact, increased cutting forces, and high tool wear. Excessive activity results in an aggressive attack on metallic surfaces and causes chemical wear of the tool, stained workpieces, and in most instances, damage to the machine tool structure as well. The temperature, largely governed by the cutting speed for a given operation, influences the reaction kinetics for film formation. At slow speeds encountered in broaching, there is time for chemical reaction to occur at the cut surface of the chip as well as maintaining a film on the cutter surface. Operations conducted at higher speeds have less time for film formation reactions on the chip surface and the process must rely on maintaining a complete film on the cutter during the period of tool/chip contact. Attempts to increase reaction kinetics by reducing cooling capabilities to raise the reaction temperature results in cutter failure through thermally related mechanisms.

Grinding operations are even more difficult with regard to cutting fluid selection and are complicated by three additional considerations beyond those inherent in macro chip operations. First, the effective rake angle of an abrasive grain has approximately 60° negative rake as compared with $+15^{\circ}$ to -5° rake angles of cutting tools. As a result, specific energy consumption (HP per cubic inch of chip produced) is higher by an order of magnitude over milling or turning operations. Second, cutting speeds are also higher by an order of magnitude thus reducing the time available for film formation on the newly generated chip surface. The third consideration involves the nature of the cutting instrument itself. Most cutting fluid additives are designed to produce films on metalic materials, not on ceramic abrasives. Welding between ceramics and workpiece materials is, however, less of a problem than metal-metal contact phenomena in cutting.

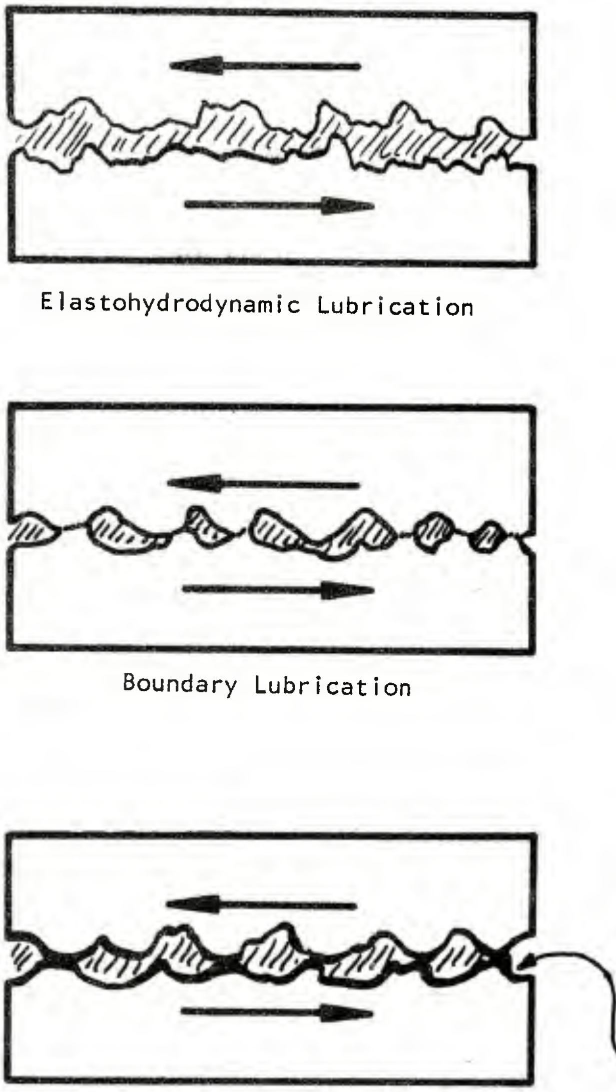


Figure 2.1-1. Schematic illustration of three basic types of lubrication mechanisms.

Experiments were conducted at TRW in which the workpiece was anodically polarized within the passivation region in an effort to enhance film development during grinding. No improvements were noted in grinding forces, wheel wear, or surface finish when the test data were compared to an identical test sequence on an unpolarized specimen. A considerable volume of experimental data, however, exists which conclusively established that additions of sulfur, chlorine, phosphorous, and fatty acid compounds to water emulsions or straight oils do indeed result in performance improvements. Since reaction kinetics were inadequate for simple solid film lubrication mechanisms, an alterate mechanism must be operative. Discussions with Professor Milton Shaw, University of Arizona, Tempe, Arizona, confirmed our earlier indications that sulfur and chlorine compounds altered the mechanical properties of the workpiece material and reduced its flow stress as the chip was developed. Addition of sulfur and chlorine compounds sparingly to the surface of a bar prior to machining has been shown to reduce cutting forces. These materials were added such that no lubrication effects between the tool and chip were possible, thus limiting all effects to the chip deformation process. This phenomenon provides an explanation of the role additives play in metal removal at speeds which preclude formation of low shear strength films on the cut surface of a chip or reaction on a ceramic tool.

An awareness of basic mechanisms operating as a result of cutting fluid interactions with metal removal events has provided a broad technology base for effective utilization of this background for in-shop cost reduction activities.

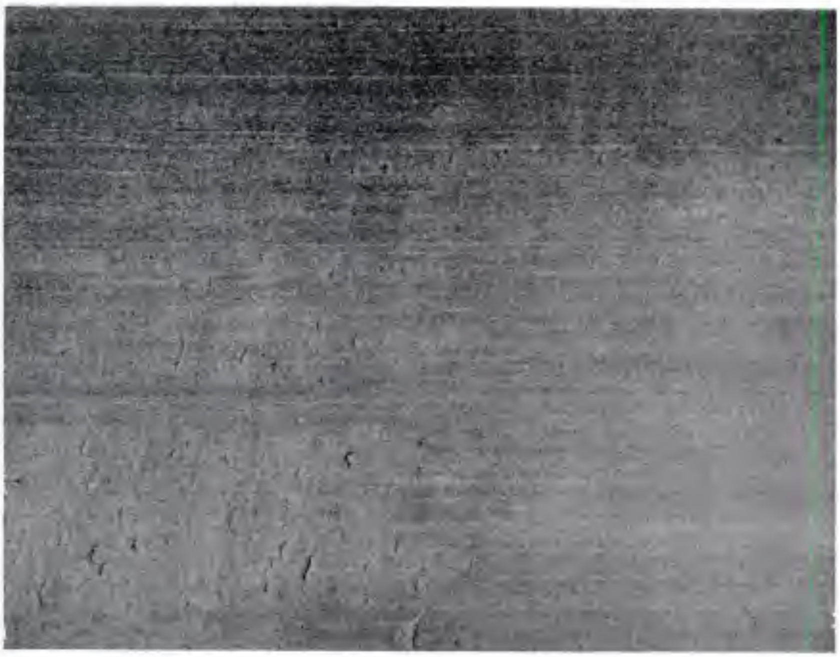
2.1.2 Implementation Technology Examples

The background technology reviewed in the previous sub-section has been successfully employed in improving production broaching and turning procedures.

A broaching operation involving cutting of rectangular pockets in heat treated 4340 steel parts was optimized by cutting fluid compositional modifications. The existing broaching oil was replaced with a mixture of Shell's Garia H with 30% Master Chemical's Magnudraw 150L. The fluid flow volume was also amplified from 3 to 20 gallons per minute. The as-machined surface finish was improved from 120-150 μ-in AA to 30-34 μ-in AA and broach tool life was increased tenfold. The change in surface quality is illustrated in Figure 2.1-2 for parts obtained from lots broached prior to and following the optimization procedure. The tearing clearly evident on parts produced prior to the investigation was traced to welding effects caused by metal-metal contact during inadequate boundary film lubrication conditions. Perhaps overshadowed by the striking process improvements is an equally important point, that this achievement was realized with commercially available cutting fluids. The implication is that adequate fluid chemistries are already available and the problem is one of matching the application with the proper product, not developing yet further new compositions.

A more comprehensive analysis was conducted to analyze another broaching operation. This analysis involved a production operation which generated complex forms on Greek Ascoloy forgings. Overall tool life of the twelve inserts comprising the tooling package required for this operation averaged 4000 parts prior to the analysis. Cutter breakage was also a serious problem in that a slotting insert was experiencing

INITIAL CONDITION



AFTER OPTIMIZATION

Figure 2.1-2. Comparison of 4340 steel part finish improvements achieved by cutting oil modification.

catastrophic failure after only 200 to 300 parts were produced. This failure necessitated removal of the tooling package some ten times between overall resharpening operations for insert replacement and fixture repair. Tests on the shop floor tend to be very costly, interfere with production, and are subject to poor controls. A more effective solution was to conduct controlled tests in the laboratory using a highly instrumental simulation facility. A close-up view of the tool holder containing a three-axis force dynamometer is presented in Figure 2.1-3. Major advantages offered by this facility include accurate duplication of factory cutting conditions, low-cost tooling and workpiece requirements, full access to the cutting zone for data acquisition, and simple means to vary cutting fluid composition and application methods.

Investigation of the slot cutter problem and tool wear rate was conducted by designing an experimental matrix to simultaneously evaluate the influence of cutting oil additive variations and tool materials on process responses. These responses included tool wear rates, cutting forces, and part surface finishes. Results of an extensive statistical analysis of the large volume of data produced revealed that a 2% sulfur, 2% chlorine, and 10% lard oil addtive package was optimum for the light cuts (low TTP factor) in the finishing portion of the cutter. However, optimum performance in the roughing zone (high TTP factor) required 10% sulfur, 10% chlorine, and 30% lard oil. These results posed a dilemma in that both fluid requirements were necessary for the same cutter. A solution was provided by Stuart's Oil No. 6736, which has a total additive package comparable to that required for the roughing zone. The sulfur and chlorine were provided as a two-stage package with 2% active and the remainder in the combined form. Release of the combined sulfur then only occurred during the higher temperatures prevailing in the roughing portion of the cut. This provided the proper composition for the finishing zone without excessive tool attack. Installation of the improved oil in a production broach produced a tool life of 32,000 pieces (an eightfold improvement) and the previous breakage problem was eliminated.

A grinding problem involving surface integrity defects in M-50 steel was analyzed (1,2). A close examination of the as-ground surface revealed minute tears present on the as-ground surface. The tears were produced by steel particles adhering to the grinding wheel being rewelded to the part surface and subsequently torn away as the wheel passed over the race. This effect has been described by other investigators (3, 4, 5) but were attributed to excessive depths of cut. Their recommendation was to reduce grinding rates below certain critical levels. This solution is economically unattractive. Further study of the problem at TRW suggested that an improved grinding fluid would eliminate the tearing by keeping the wheel free of adherent metallic swarf. Substitution of the existing fluid with a more highly compounded product was fully successful in resolving the rewelding condition in conjunction with providing more chip clearance in the grinding wheel structure. Figures 11 and 12 illustrate the appearance of the as-ground surfaces and the grinding wheels for the previous and optimized processes, respectively. The improvement in surface quality is strikingly apparent from the figures. In addition, the swarf and adhering metal clogging and the grinding sheel (Figure 2.1-4) have been completely eliminated (Figure 2.1-5). An important further

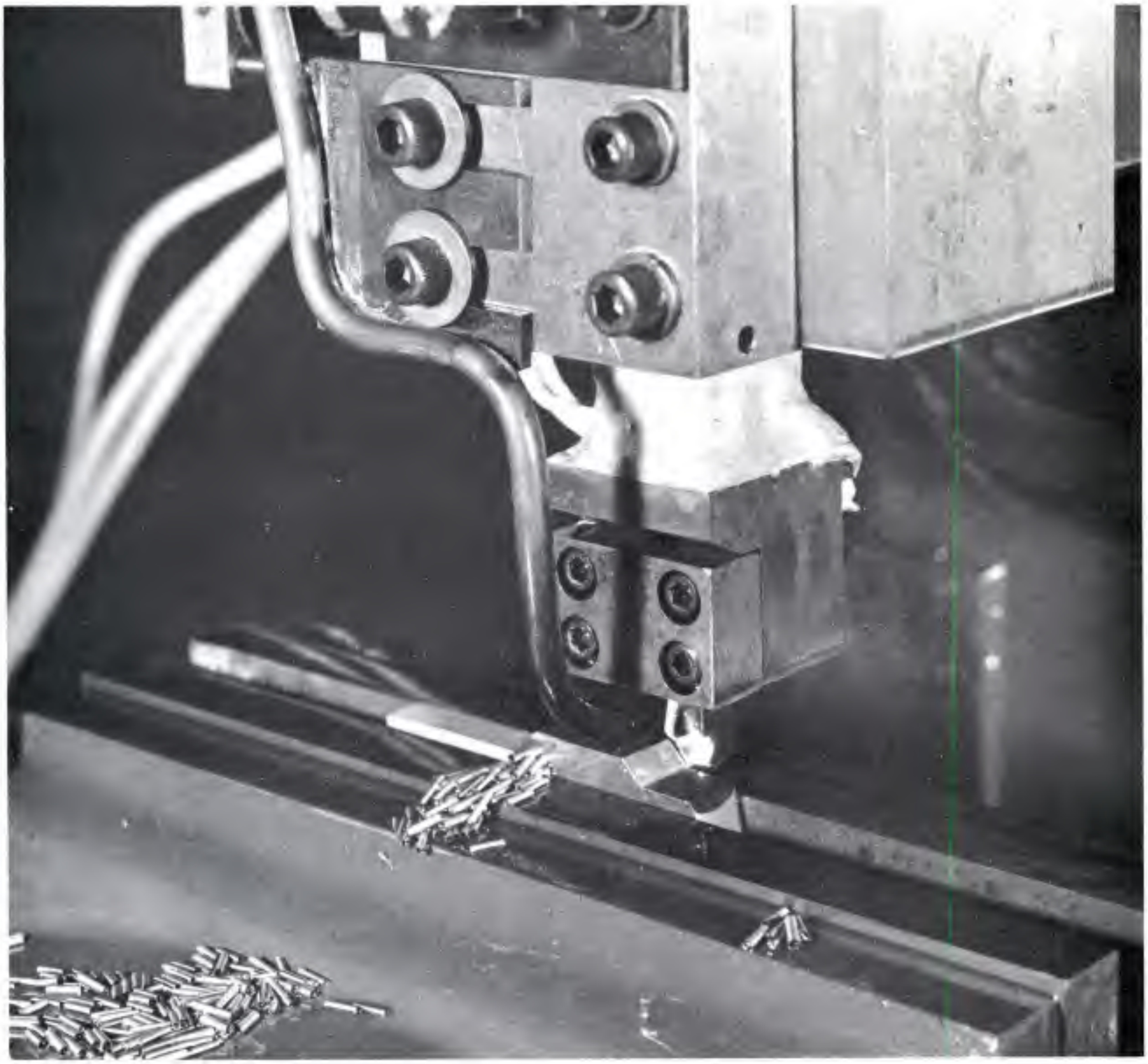
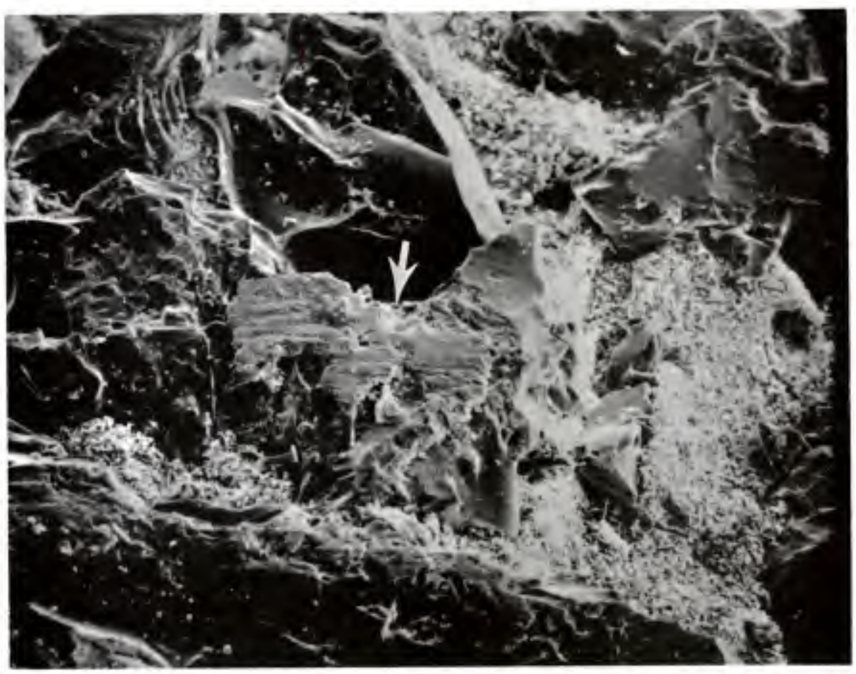


Figure 2.1-3. Close-up of instrumented tool holder on laboratory broaching simulation facility located in the TRW Machining Research Laboratory.

M50 Steel Part 1000X



Worn Wheel 200X

Figure 2.1-4. SEM photomicrographs of the appearance of an M50 steel part and the surface of the worn grinding wheel used with Kutwell 40 grinding fluid.

M50 Steel Part 1000X

Worn Wheel 200X

Figure 2.1-5. SEM photomicrographs of an M50 steel part and the worn grinding wheel used with Hocut 3210 fluid.

benefit was realized in that the more highly compounded product provided a much freer cutting action which permitted a 55% reduction in floor-to-floor production cycle time. It should be emphasized that provision of a more open grinding wheel structure alone was not effective in resolving the problem. It is absolutely essential that a systematic investigation including all relevant factors be employed to achieve lasting process improvements.

Recognition of various mechanisms which contribute to net tool wear is a valuable asset in the interpretation of worn cutter topographic and subsurface effects. The well known tool wear relationships, shown in Figure 2.1-6, schematically illustrates the relationships of various factors which interact to varying degrees to produce wear as the cutting speed increases. An example of the results of applying these principles will be discussed to illustrate the potential for process improvement. This example deals with a turning operation using carbide inserts to machine Nitralloy 135M bar stock. Insert failures involved BUE and chipping mechanisms which necessitated frequent tool offset adjustments and insert changes, Figure 2.1-7(a). Modifications to the process cycle, including a change in fluid chemistry, altered the wear mechanism to one of gradual crater development with virtually no edge wear, Figure 2.1-7(b). This latter wear mechanism resulted in an insert life without loss of dimensional control which was seven times longer than the previous condition.

2.2 Technical Approach

The objective of Phase I of the Rock Island Arsenal's "Studies to Establish a Cutting Fluid Control System" and to develop a preliminary Cutting Fluid Application Matrix. This matrix will be designed to provide the RIA with the ability to select an adequate cutting fluid for existing and future manufacturing processes. In order to accomplish this, two basic steps were taken: data collection and the test design and evaluation. The following subsections will describe these steps.

2.2.1 Data Collection

In order to develop a preliminary cutting fluid matrix, data had to be gathered from the RIA. Each manufacturing process performed at the Arsenal must be analyzed and when possible tool samples will be collected. Then a severity index will be developed to classify the different types of manufacturing processes observed and to relate them to the other manufacturing processes performed throughout the arsenal.

Once these data are gathered, a survey of the commerically available cutting fluids will be initiated. As many cutting fluid manufacturers will be contacted as feasible and asked to recommend products for RIA. They will be required to complete a detailed questionnaire for each neat oil product and water soluble product recommended. A computer program will be developed to analyze the information supplied by the cutting fluid manufacturer. Concurrently, preliminary screening tests will be performed on test fluids submitted by the cutting fluid manufacturers. These preliminary tests will include a rust test, a test for resistance to RIA bacteria and a residue test. These tests will be utilized to eliminate products exhibiting fundamentally undesirable properties. Also, telephone contact will be made with all the participating

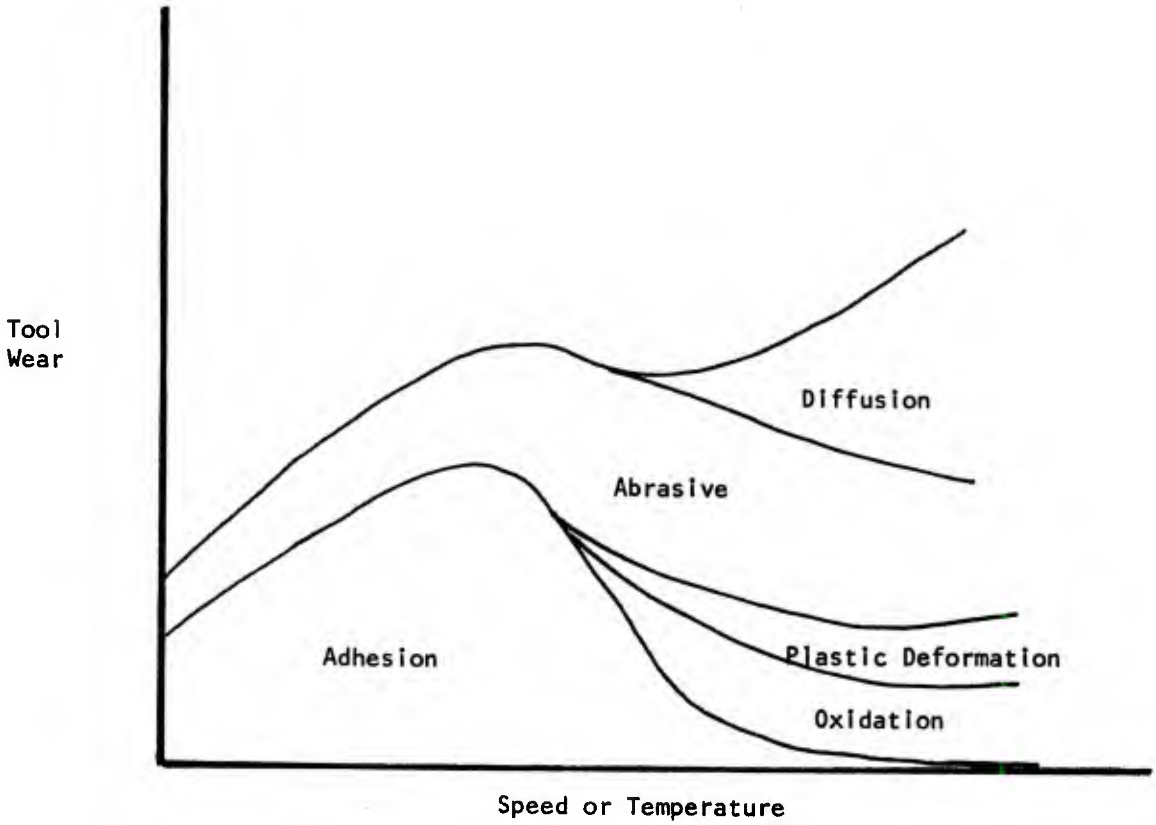
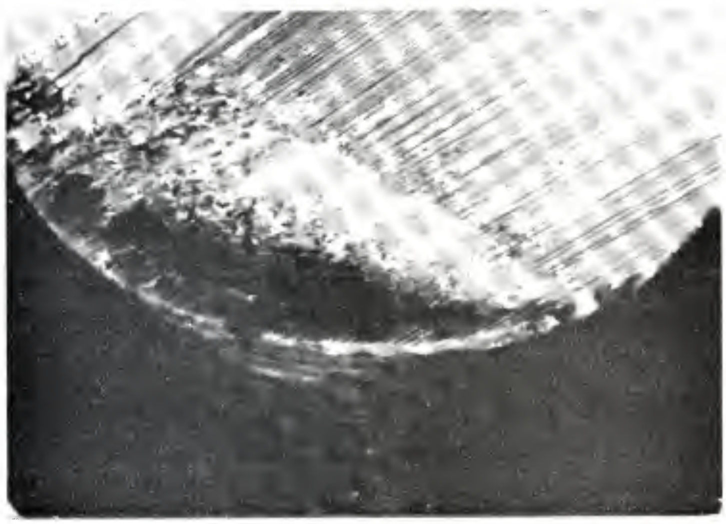


Figure 2.1-6. Illustration of relationships between cutting rates and various wear mechanisms.

a) ORIGINAL WEAR - CHIPPING AND WELDING



b) AFTER ANALYSIS - GRADUAL CRATER WEAR

Figure 2.1-7. Scanning electron microscope (SEM) micrographs of carbide inserts showing wear mechanism change providing a seven-fold tool life improvement.

fluid manufacturers to gain insight into the chemical and physical makeup of their products. As many interviews with the chief chemists of the fluid manufacturers will be held as possible. This will enable Machining Technology to learn the chemistry of cutting fluids passing the initial screening tests and how best to apply them.

2.2.2 Test Design and Evaluation

After researching, the area of cutting fluid application and studying the RIA manufacturing survey with the severity index, initial test fluids will be chosen. Initially, these fluids will be grouped into three categories using manufacturer supplied data: heavy duty, medium duty and light duty. Also, each category will be subdivided into generic subgroups. Each manufacturing process studied will be tested with three generic types of cutting fluids: emulsions, semi-synthetics and full synthetics of the category applicable to that machining process.

An emulsion or soluble oil is a cutting fluid containing approximately forty to sixty percent oil. Emulsions are generally opaque and have the ability to mix in both water and oils. Semi-synthetics typically contain from five to twenty percent oil and are translucent. As with emulsions they have the ability to mix with water or dissolve oil. Full synthetics contain no natural oil and most full synthetics are immiscible with oils. They are generally transparent due to the fact full synthetics are true solutions.

The selection process for the preliminary application matrix will involve design and performance of a series of metal removal tests. These tests will consider all major manufacturing processes currently in use at RIA and will utilize the same range of metal removal parameters. The candidate fluid products will be evaluated by the following processes, in each case, the variables to be controlled or monitored are indicated.

1. Grinding;

   a. Wheel Grade
   b. Wheel Speed
   c. Table Speed
   d. Cross Feed
   e. Total Depth of Cut
   f. Infeed
   g. Wheel Dressing Method
   h. Material

2. Turning and Boring;

   a. Tooling
   b. SFM
   c. Feed
   d. DOC
   e. Material

3. Milling;

    a. Tooling
    b. SFM
    c. Chipload
    d. Feed
    e. Cutter Diam.
    f. DOC
    g. Material

4. Drilling;

    a. Tooling
    b. SFM
    c. Feed
    d. Hole Geometry (Diameter, Depth)
    e. Material

Force data will be collected during metal removal tests using a Honeywell 1858 Visicorder which utilizes light sensitive paper and fiber optics. This instrument has a much faster response time than a conventional chart recorder. The additional response time will allow for more representative data to be collected. Force information will be supplied to the Visicorder by Kristal Instruments piezoelectric machining dynamometers. Piezoelectric dynamometers provide a higher frequency response capability than conventional strain gages, thus supplying additional information for data analysis. Instantaneous horsepower consumption will be measured with a Hall-effect wattmeter connected to the spindle motor windings. Velocity measurements will be taken using an LVT (Linear Velocity Transducer).

The cutting fluid evaluation will take into account the following factors:

1) Dynamometer forces
2) Power consumed during machining
3) Tool wear
4) SEM evaluation of the tool

Fluids that show lower forces, minimum power consumption and the least tool wear will be evaluated as being technically superior. Additional considerations to be included in the selection process will include installation costs, operator acceptance, maintenance and disposal requirements.

3.0 RESULTS AND DISCUSSION

The Phase I program results are discussed in this section. Due to the program complexity, discussion of these results has been subdivided into a number of individual elements. These elements fall into three basic categories: analyzing RIA operations and requirements, commercially available cutting fluids, and test results. Each element describes an individual aspect of the overall program and they have been organized to follow sequentially in a logical manner. Continuity of the discussion for each manufacturing process is therefore maintained and the accompanying analysis can be more specialized for each case treated. Further, each element can be examined on an individual basis without detraction from the report as a whole.

This section will begin with an in-depth analysis of the current RIA manufacturing processes. These data are then further refined into a preliminary severity index for the Arsenal. Background information about cutting fluids and their manufacturers will be presented next. Also, the general criteria for cutting fluid test selection will be discussed. Following these subsections, other subsections will therefore treat grinding, turning, milling, drilling, broaching, and tapping cutting fluid testing sequentially. The final subsection will present a preliminary cutting fluid application matrix.

3.1 RIA Manufacturing Survey

The most important part of developing a preliminary fluid application matrix is characterizing the manufacturing processes the matrix will be applied to. This section will outline how this was accomplished and summarize the manufacturing survey's findings. The following three subsections describe process data analysis, analysis of observed tool wear, and observations made of the current cutting fluid application systems.

3.1.1 Process Data Analysis

During the Phase I program activity, a series of surveys were made at RIA to develop a comprehensive data base describing manufacturing operations being conducted at the Arsenal.

This was a very important phase of the program. The data gathered would be used as guides to structure the machining tests as well as establishment of a basis for selecting trial cutting fluids. Great care was taken in order to select representative data. The parts and operations were chosen after many discussions with Rock Island Arsenal's general management, and line foremen from first and second shifts. A specially designed data sheet was developed that would insure that all the pertinent data about any given machining operation would be obtained. An example of this sheet, used to describe a turning operation, may be viewed in Figure 3.1-1.

PART NUMBER: 12007623

OPERATION: Turn OD — Severity: High Med Low

MATERIAL: 4130 Steel CO Tube — Hardness: Rc 25 to Rc 30

EQUIPMENT: #823861 American Tracer — LOT QUANT: 196 Min. -- Max.

CURRENT FLUID: Type: Water — Name: Trim Sol — Mfr. Master Chemical

Concentration: 30 : 1

MACHINING DATA:

CONFIGURATION: Cylinder 40.5 inches long, 3.625 inches diameter

	Min. Rough	Max. Finish
SFM:	256	302
DIAM.WORKPIECE:	3.625	
RPM:	270	318
FEED RATE:	0.0173	0.0173
DEPTH OF CUT ROUGH:	0.250	
DEPTH OF CUT FINISH:		0.0125
H.P.:	10	

TOOLING DATA:

GEOMETRY: Carbide Insert Triangle 516 TNMG 543E

NO. OF CUTTING EDGES: 6 — CHIP BREAKER ON TOOL: YES ✓ NO

MFR: Carboloy — NEW TOOL COST: $7.11

CURRENT LIFE: Min: 5 pcs/edge — Max.

TOOL CHANGE TIME: 1 min. — OPERATOR COST: $43.72

NEED SETUP MAN: No ✓ Yes — SETUP MAN: $ DNA /Hr.

HOW FLUID IS APPLIED TO PART: Applied to top of part and tool through a nozzle that moves with cutting tool. Adequate fluid flow was observed.

4.7.80

Figure 3.1-1. Cutting Fluid Test Data Sheet for Turning

This sheet contains information such as the feed, speeds and depth of cut of the machining operation. Such information aids in determining the heat buildup, the type of chip loading, and forces the cutting tool may be experiencing. The hardness of the workpiece was also examined. The hardness level is important in determining what cutting temperature the cutting tool may experience as well as helping to evaluate the cutting tool geometry and required surface speed. Part of the form is devoted to tooling and tool geometry. This information is necessary in order to determine the optimal method of cutting fluid applications. Whenever practicable, representative tooling samples were secured to study the wear characteristics.

During the visits, 76 individual machining operations were observed. These operations had been performed on 24 different parts. Most of the observations were of milling, turning, grinding and drilling operations. Data were also obtained which showed that these four basic operations represent 91% of total monthly operating hours, Table 3.1-1. The specific machining operations and parts studied are displayed in Table 3.1-2. Over 95% of these parts are manufactured from 4100 series steel. Therefore, these results indicate that the primary emphasis of the cutting fluid analysis be focused on the manufacturing of parts with 4100 series materials. Final fluid selections will include considerations for efficient machining of non-ferrous alloys.

Such a course of action would maximize Rock Island Arsenal's rate of return on its cutting fluid contract investment. This position may be emphasized by the following illustration. Suppose that a special cutting fluid could increase tool life for non-ferrous machining by 100%. The cost savings generated by this new fluid would only be a fractional percentage of the potential cost savings that could be realized by achievement of a 5% increase in life for tools machining ferrous materials by using products tailored primarily for the 4100 series alloys.

The data gathered at RIA are being used to define the severity of each operation observed. The severity analysis will then be used to develop the exact parameters which will be used to simulate the observed machining operations at Machining Technology's Laboratory. The objective of this analysis will be to develop a cutting fluid and machining severity index that will match cutting fluid properties with machining characteristics. This requires that a quantitative index be established which defines the relative severity of machining operations at the Arsenal. The index combines cutting parameters, tool design, and material properties such that the various operations can be ranked. Development of a preliminary index has been accomplished and a discussion of the formulation rationale is presented in section 3.2. The first step in developing the severity analysis was to study the tools collected at RIA. In the next section, 3.1.2, Observed Tool Wear, the methods of tool wear and how they affect the various machining operations are discussed.

3.1.2 Analysis of Observed Tool Wear

The type and severity of tool wear is a very important factor to consider in the selection and application of a cutting fluid. A modification of a particular tool's wear mode by a cutting fluid can drastically increase tool life. This section will explain the four basic types of tool wear modes and then analyze the tooling samples collected at Rock Island Arsenal.

TABLE 3.1-1

TOTAL MONTHLY HOURS OF THE BASIC MACHINING OPERATIONS PERFORMED AT ROCK ISLAND

Basic Operation	Hours Operation Per Month	% of Total Hours
Turning & Boring	40,000	31
Milling	37,000	29
Grinding	30,400	23
Drilling	10,100	8
Sawing	6,500	5
Planing	3,000	2
Broaching	3,000	2
Total	130,000	100

TABLE 3.1-2

SUMMARY OF DATA GATHERED AT RIA

Operation Type	Part Number	Number of Different Operations Observed	Material
N/C Turning	8449036	30	4100
N/C Turning	8382446	1	4100
N/C Turning	10895646	1	4100
Turning	10891793	1	4100
Turning	10956584	1	4100
Turning	12007666	1	4100
Turning	12007623	1	4100
Turning	8449307	2	4100
N/C Milling	8449309	10	4100
Milling	7133213	1	Stainless
Milling	7793063	1	4100
Milling	7791379	1	4100
Milling	6532032	1	4100
Milling	10884271	1	4100
Tapping	8449309	4	4100
Drilling	8449309	8	4100
Boring	5507239	1	4100
Boring	8449307	2	4100
Boring	6508894	1	4100
Broaching	7793146	1	8169
Broaching	10892198	1	4100
Grinding	10901204	1	4100
Grinding	6538758	1	4100
Grinding	6538757	1	4100
Grinding	12007805	1	4100
Grinding	12012329	1	4100

3.1.2.1 The Basics of Tool Wear

The four basic types of tool wear are built-up edge (BUE), cratering, flank wear and chipping. These will be explained by the following:

1. Built-up Edge

This phenomenon predominantly occurs at lower cutting speeds. The locally heated workpiece material welds itself to the tool cutting edge. Such a buildup causes a poor surface finish to be generated on the workpiece. The tool essentially experiences little or no wear, but cutting forces are high and the part surface finish is generally undesirable. As this material buildup continues, two events may occur; the metal accumulation may come off the tool and reattach itself to the workpiece with no effect to the cutting tool or pull off a portion of the tool. A picture of a cutting tool with built-up edge is displayed in Figure 3.1-2(a).

2. Cratering

Cratering is a natural tool wear action where chips rubbing across the top of the cutting tool behind the cutting edge on the rake face cause a depression to be formed. This action is caused by the degradation of the cobalt binder and loss of carbide particles from the matrix. The surface recedes by a combination of binder erosion, plastic deformation due to thermo-mechanical processes and oxidizing adhesion, and other wear mechanisms. An efficient cutting fluid will reduce this mode of tool wear by providing a low shear strength film which aids in separating the tool and chip. An example of cratering is displayed in Figure 3.1-3.

3. Flank Wear

Flank wear is a common form of cutting tool wear. The rate at which it occurs greatly affects tool life. Flank wear results in high forces and loss of size control. As the flank of a tool wears, there is increased heat buildup due to friction. This may also affect the dimensions of the finished part the tool is cutting. Flank wear occurs on the surface below and immediately adjacent to the cutting edge (Figure 3.1-2(b)). Flank wear can be minimized with a copious flow of a cutting fluid designed for the machining application. This action will help to carry off the heat generated at the tool/workpiece interface.

4. Chipping

This process occurs by a discrete sequence of events and represents a severe case of normal BUE effects, the first of which is that a relatively strong weld develops between the tool and the workpiece at or near the cutting edge. Continued flow of metal causes some additional buildup in this area, commonly referred to as built-up edge (BUE). Then this region is torn away in the chip stream, removing a portion of the cutter in the process. This sequence can occur in a microscopic scale or in a larger scale as aggravated by vibration induced by machine/tool/part rigidity problems.

Built-up Edge

(a) 10X

Flank Wear

(b) 10X

Figure 3.1-2. An Example of Built-up Edge and Flank Wear.

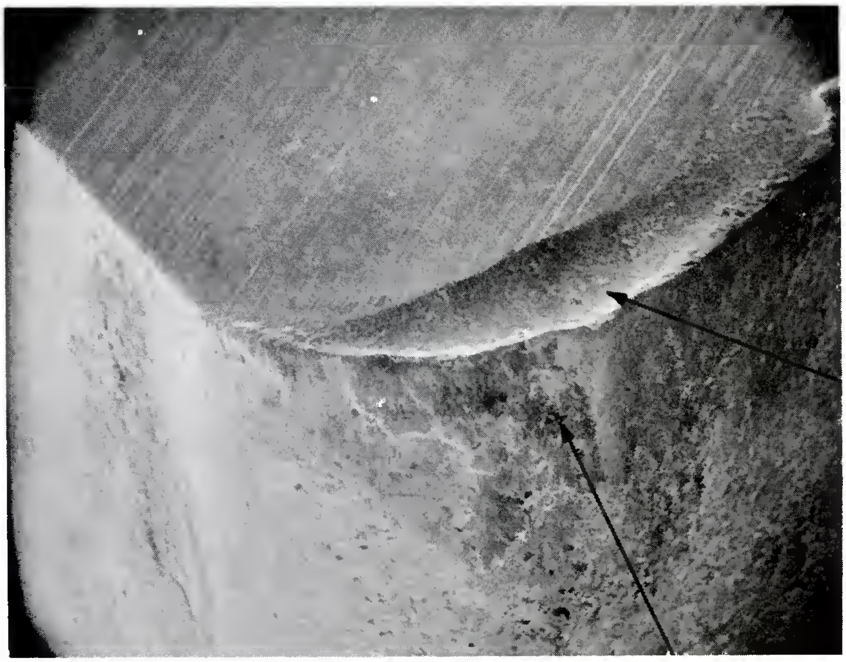


Figure 3.1-3. An Example of Cratering.

Another reason for chipping may be a leaching effect of the cutting fluid on the cobalt binder of the carbide tool. This condition may be improved with an adequate cutting fluid which will provide a low shear strength film that will separate the tool from the chip. Also, the fluid will carry away heat from the cutting tool. An example of this is displayed in Figure 3.1-4.

It is desirable to have a balance of types 2 and 3 (crater and flank) wear modes to fully utilize the potential life of a given cutting tool. For instance, excessive flank wear is indicative of poor lubrication properties; similarly, excessive cratering results from heat buildup. A satisfactory cutting fluid will provide a balance between these two wear modes so that they occur simultaneously at a gradual rate.

3.1.2.2 Analysis of the Observed Tool Wear Modes

Various analytical tools in machining phenomena were used to analyze the data brought back from RIA. The use of SEM pictures and optical microscopic techniques were used to determine what physical phenomena caused the various modes of tool wear observed. Along with the analytical methods used, studies were conducted to establish what effects the machining parameters and machine conditions observed at the arsenal had contributed to the modes of tool wear observed. The following parameters were thoroughly studied before any conclusions were established for each basic machine operation evaluated:

1. Speed, feed, depth of cut or chip load;
2. Metal removal rates;
3. Tool and machine rigidity;
4. Hardness of workpiece materials;
5. Cutting fluid type and concentrations employed;
6. Methods of cutting fluid application; and
7. Types of tools used and their composition.

After fully considering these parameters, the following conditions or combinations of conditions, appear to be major factors in machining productivity at the Arsenal:

1. Selecting a non-optimum cutting fluid for the observed feeds and speeds;
2. Utilization of cutting fluids which deviated significantly from the manufacturer's recommended concentration levels;
3. Supplying the cutting fluid in an insufficient quantity at the tool/workpiece interface which reduces the effectiveness of the cutting fluid;

Figure 3.1-4. An Example of Chipping.

4. Operating the machining equipment at speeds and feeds which do not take full advantage of the total capabilities that the tooling utilized was designed to achieve; this action may cause premature tool failure to occur;

5. Utilizing non-rigid tooling which can cause detrimental vibrations;

6. Using too hard a grade of carbide for the particular cutting operation; and

7. Utilizing a cutting fluid that may be leaching out a small amount of the cobalt binder on the carbide cutting tool causing it to weaken.

The applicability of these general conditions to the various machining operations and their individual modes of tool wear will be discussed in the following subsections according to generic process types.

Turning and Boring

Seventy-five percent of the observations for turning and boring exhibited either extreme wear due to chipping or extreme wear due to cratering without evidence of flank or BUE effects (see Table 3.1-3). This observation indicates that the desired balanced wear between cratering and flank wear is not being achieved. Examples of the observed extreme crater wear for turning and boring may be viewed in Figure 3.1-5. The scanning electron microscope (SEM) photomicrographs indicate that excessive crater wear and minimal flank wear are already evident.

An example of the proper balance between tool flank wear and cratering in a turning operation was observed in Shop M's turning department (see Figure 3.1-6). Here, crater and flank wear rates can be seen to be approximately equal and both tool faces exhibited uniform recession. This shows that the correct balance between surface speed, feed and tool geometry with an adequate cutting fluid application was achieved in this example.

On-site observations indicated that the present methods for physical fluid application appeared to be adequate. Sufficient cutting speeds for carbide tools, 300-600 SFM, for the most part were achieved which essentially eliminated the possibility for the built-up edge mode of wear. The exceptions were when older low-speed machines were utilized. In some cases, tool rigidity or using too hard of a carbide grade may have also contributed to initiate chipping. Insufficient concentration of the present cutting fluid or the utilization of an inadequate cutting fluid has the highest probability of being the primary cause of premature tool failure by the undesirable chipping mode.

Milling

All of the observed tool wear was in the form of chipping (see Table 3.1-3). An example of a chipped milling cutter may be observed in Figure 3.1-7. Notice how minimal the other forms of tool wear are in comparison to the microfracturing of the cutting edge. This mode of tool failure can be caused by using a slower surface speed

TABLE 3.1-3

Observed Tool Wear Modes

Operation	Part No.	Wear Mode
N/C Turning,"Facing"	8449036	Chipping
N/C OD Turning	8449036	Cratering
N/C Turning	8449036	Cratering
Turning Ceramic Tool	10891793	Chipping
Turning OD	12007623	Good
Bore ID	8449307	Cratering
Bore ID	5507239	Good
Bore ID	6508898	Chipping
N/C Face Milling, Dry	8449309	Chipping
N/C Side Milling	8449309	Chipping
N/C Side Milling	8449309	Chipping
N/C Whisper Cut	8449309	Chipping
Milling, End	6532032	Chipping
Face Milling, Dry	7793063	Chipping
	Total	14

Chipping = 9/14 = 64%

Cratering = 3/14 = 22%

Good = 2/14 = 14%

Figure 3.1-5. Crater wear observed during N/C OD turning of Part No. 8449036. Material: 4130 centrifugal casting; Hardness: 170 to 248 BHN; SFM: 781; Feed: 0.026 in/rev; D.O.C.: 0.140 inch; Fluid: Trimsol 30:1; Tool: Coromat TNMM 543 71 015; Machine: American N/C lathe, #28029.

Flank Wear

Crater Wear

Figure 3.1-6. An example of the desired balance between crater wear and flank wear. Observed during turning of Part No. 12007623. Material: 4140 steel tube; Hardness: R_c 25-30; SFM: 256; Feed: 0.0173 in/rev; D.O.C.: 0.250 inch; Fluid: Trimsol 30:1; Tool: Carboloy 516 TNMG 543E; Machine: American Tracer Lathe 823681.

Chipping observed during vertical boring of Part No. 8449307. Material: 4140 steel forging; Hardness: R_c 26-32; SFM: 237; Feed: 0.015 in/rev; D.O.C.: 0.125; Fluid: Trimsol 30:1; Tool: Sanvic SNG 633-1025-82464; Machine: Bullard #21560.

Chipping observed during N/C milling of Part No. 8449309. Material: 4140 steel casting; Hardness: NHS; SFM: 629; Feed: 8 in/min; Chip Load: 0.002; Fluid Trimsol 30:1; Tool: Insert #SPG-422B; Tape: MM027A; Tool: 0914; Machine: K&T N/C Mill #2252.

Figure 3.1-7. Examples of Chipping.

than for which the cutting tool was designed. Another reason could be a lack of rigidity in the setup. The most probable cause of chipping is insufficient cooling or lack of lubrication at the tool/workpiece interface. This condition may be caused by applying cutting fluids to the tool/workpiece interface in insufficient quantities, using an inadequate cutting fluid for the machining operation or utilizing a cutting fluid below its recommended concentration level. All of the N/C milling equipment seemed to provide adequate cutting fluid flow on the tool and workpiece. However, many of the older milling machines in Shop M had minimal fluid flow and, in some cases, operations were run dry. Many operations were observed having lower than recommended cutting fluid concentration levels.

Broaching

Broaching is largely utilized in rifling operations on gun tubes. The high pressure method of cutting fluid application was regarded as excellent. In most cases, the job lot sizes are such that the broach bar does not require resharpening during the part production run. Broach bars on long runs are removed for resharpening when surface tearing is noted on the groove portion of the rifling. This minor problem can be readily corrected by introducing a sulfur and chlorine bearing additive to the Topaz oil such that the total sulfur and chlorine/bromine content is approximately 3-5%. Major changes in these operations are not anticipated.

Grinding

Grinding operations observed at RIA were found not to be particularly severe with regard to heavy cuts on high rates of stock removal. Most operations involved preparation of surfaces for chrome plating, which required fine finishes and accurate dimensional control. Because of the relatively mild grinding parameters and the low strength of the unhardened 4100 series steels, wheel attrition has not been a problem and frequent dressings to restore form are not required. Loading of the grinding wheels was observed, however, and improved fluid compositions would be effective in increasing grinder productivity by generation of the desired finishes more rapidly.

3.1.3 Observations Made of the Current Cutting Fluid Application Systems

Currently, RIA is utilizing individual sumps to supply cutting fluid at each machine location. This method has the advantage of being able to utilize different cutting fluid types or concentration levels which has the potential to optimize the cutting fluid application for an individual machine. A second advantage is that a cutting fluid system failure affects only one machine, unlike a central system which may result in shutdown of an entire shop.

The major cutting fluid used at RIA is Master Chemical's Trimsol, and make-up fluid is provided at a 30:1 dilution ratio. A Venturi type mixer is used to dilute the concentrate directly from the drums supplied. Maintenance of the machine sumps is the responsibility of each department foreman. Most department foremen check their sumps with a refractometer. The main reason for changing cutting fluid in the sumps at the Arsenal is reported to be due to development of a "foul smell." This information was acquired from personal observations and interviews with department foremen and machine operators. Also, no one interviewed ever remembered observing the situation where a fluid had been in place so long that the emulsifiers had been depleted, causing an emulsion split.

In general, most of the turning and boring operations did not utilize the 19:1 dilution ratio that Master Chemical recommends for Trimsol. Also, the grinding sumps observed using Cincinnati Milacron's Cimfree 238 did not contain its recommended dilution ratio of (25-30):1. The ratios used on these machines were below the reliable detection limit of the refractomer. This dilution ratio is marginally adequate to prevent rusting of the workpieces and grinding machines. Many of the observed grinding machines had rust problems and sludge buildup in their sumps.

3.2 RIA Preliminary Severity Index

The objective of this portion of the program is to establish a quantitative methodology of ranking metal removal operations. The ranking system is intended to group these operations relative to their severity such that specific cutting fluid properties can be established for each of these groups. The work accomplished in the Phase I program effort has permitted establishment of a preliminary system for assignment of severity indices to individual operations within process classes, such as turning, milling, and grinding, and to weigh these indices for interclass comparisons.

3.2.1 Basic Data

The data collection sheets, such as shown previously in Figure 3.1-1, that were completed during the 28 April 1980 visit were consolidated into a summary form. These data appear in Tables 3.2-1 through 3.2-7 for each class of machining operations. In each case, the columns across the top of the data tabulation refer to key parameters associated with the various process classes.

After studying the process data analysis sheets, some machining operations' severity is quite apparent. For example, the turning operation in Table 3.2-1 for part number 8382446, which has 848 SFM, 0.140 inch depth of cut, 0.026 inch/revolution feed rate, and a metal removal rate (MRR) of 37 cubic inches per minute, seems to be severe, especially compared to part number 8449036 whose SFM = 781, depth of cut = 0.020 inch, feed rate = 0.026 inch/revolution and MMR = 4.9.

This example shows how readily two cases of one type of machining can be compared to one another or ranked. Part Number 8382446 is the most severe operation and would receive the highest severity ranking value, and part number 8449036 would receive the lowest rank severity number. However, the goal is not to compare operations within a particular basic machining operation but to compare all the machining operations within RIA. The overall goal will be to use this machining comparison method and combine it with a similar comparison method which is being developed concurrently for cutting fluids. The end result will be a chart that will permit matching a particular machining operation to a cutting fluid at a specific concentration level.

TABLE 3.2-1

RIA Manufacturing Data Analysis Sheet for Turning

Part No.	Operation	SFM	Depth of Cut (in.)	Feed Rate	Hardness	OTW	MRR
8449036	N/C Face	422	0.005	0.013	BHN 170-248	CH	0.3
8449036	N/C Rough Turn OD	781	0.140	0.026	BHN 170-248	CR	34.1
8449036	N/C Finish Turn OD	781	0.020	0.026	BHN 170-248	CR	4.9
10891793	Turn OD with Ceramic	413	0.150	0.014	R_c25-30	CH	10.4
10956584	Turn OD with Ceramic	413	0.150	0.014	R_c29-36	CH	10.4
12007666	Turn OD	372	0.100	0.015	R_c33-35	-	6.7
12007623	Turn OD	256	0.250	0.017	R_c25-30	G	13.1
8449307	Turn OD	423	0.060	0.015	R_c26-32	CH CR	4.6
8382446	N/C Turn OD	848	0.140	0.026	R_c26-32	-	37.0
8382446	N/C Turn OD	761	0.140	0.026	R_c26-32	-	32.2
10895646	N/C Turn OD	411	0.140	0.018	R_c20-25	-	12.4

Key: SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.

TABLE 3.2-2

RIA Manufacturing Process Data Analysis Sheet for Boring

Part No.	Operation	SFM	Depth of Cut	Feed Rate	Hardness	OTW	MRR
5507239	Bore ID	197	0.125	0.013	NHS	G	3.8
8449307	Bore ID	237	0.125	0.015	R_c26-32	-	5.3
8449307	Bore ID	294	0.128	0.015	R_c26-32	–	6.6
8449307	Bore ID	316	0.060	0.015	R_c26-32	-	3.4
6508898	Bore ID	221	0.187	0.012	BHN 242-248	CH	6.0

Key: See Table 3.2-1.

TABLE 3.2-3

RIA Manufacturing Process Data Analysis Sheet for Milling

Part No.	Operation	SFM	Feed Tooth	MRR	Feed Rate	Hardness	OTW
8449309	Dry Face N/C Milling	314	0.002	60.3	4-8	NHS	CH
10884271	Dry Face Milling	702	0.003	315.9	12.5	R_c25-30	
8447309	Slot Milling N/C	314	0.005 0.008	150	3-5	NHS	
8447309	Side Milling N/C	398	0.004 0.007	267	5-8	NHS	CH
8447309	Side Milling N/C	314	0.0035 0.0026	53	3-4	NHS	CH
8447309	Whisper Cut Face Milling N/C	629	0.002	121	8	NHS	CH
8447309	N/C End Mill	60	0.0015	2	1.5	NHS	
8447309	N/C End Mill	334	0.001	40	2.0	NHS	
7133213	End Mill	62.4	0.008	12	2	NHS	
6532032	End Mill	32	0.004	3	2	NHS	CH
8449309	End Mill N/C	63	0.0016	4	3	NHS	
8449309	Bore N/C End Mill	57	0.003	6	3	NHS	
8449309	Bore N/C End Mill	64	0.001	5	6	NHS	
7793063	Face Mill Dry	650	0.002	119	7.625	R_c31-38	CH
7791379	Peripheral Mill Conventional	47	0.005 0.0047	7	2.625 2.125	R_c42-46	

Key: SFM = Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.

TABLE 3.2-4

RIA Manufacturing Process Data Analysis Sheet for Drilling

Part No.	Operation	SFM	Depth of Hole	Feed Rate	Hardness	L/D
8447309	Spot Drill	157	0.525	0.0025	NHS	DNA
8447309	Drill	59	0.863	0.0075	NHS	1.3
8447309	Drill	59	1.5	0.0075	NHS	2.7
8447309	Drill	52	0.50	0.0067	NHS	1.1
8447309	Drill	51	0.5	0.004	NHS	2.6
8447309	Drill	55	0.63	0.0096	NHS	0.8
8447309	Drill	41	1.0	0.003	NHS	6.4
8449309	Core Drill	70	3.5	0.01	NHS	DNA

Key: SFM = Tool velocity, surface feet per minute.
Feed Rate = Tool advancement rate in inches per revolution.
L/D = Length of hole/diameter of hole.
DNA = Does not apply.

TABLE 3.2-5

RIA Manufacturing Process Data Analysis Sheet for Tapping

Part No.	Operation	Hole Type	SFM	Depth of Hole	Feed Rate	Hardness
8449309	1/2-20 UNF Tap	B	26.2	1.00	10	NHS
8449309	1/4-20-UNC-2B Tap	B	13.0	0.5	10	NHS
8449309	1-8 UNC-2B Tap	B	21.0	2.62	10	NHS
8449309	10-32 UNF-2B Tap	T	16.0	1.0	10	NHS

Key: SFM = Tool velocity, surface feet per minute.
Feed Rate = Tool advancement rate, inches per minute.
Hole Type = B = Blind Hole, T = through hole.
NHS = No hardness specified.

TABLE 3.2-6

RIA Manufacturing Process Data Analysis Sheet for Grinding

Part No.	Operation	Material	SFM	Infeed	Work Speed	Crossfeed	Hardness
10901204	OD Cylindrical Grind	4140	4200	0.001	50	1 in/rev	BHN 212/248
			(new wheel)	0.0005			
6538758 or 6538757	Surface Grind	4140	6021	0.001	35	0.200/pass	NHS
			(new wheel)	0.0005	35	0.200/pass	NHS
12007805	Surface Grind	4140	6021	0.0005	60	0.130/pass	R_c 30/35
			(new wheel)	0.00025	60	0.130/pass	R_c 30/35
12012329	Cylindrical Grinder	Al-Br	6283	0.001	25	1.6 in/rev	NHS
			(new wheel)	0.0002	25		

Note: All crossfeeds are continuous and not incremental or consistent.

Key: SFM = Wheel velocity, surface feet per minute.
Infeed = Amount the grinding wheel moves radially per pass, inches.
Work Speed = The rate the workpiece moves past the grinding wheel, ft/min.
Crossfeed = Amount the grinding wheel moves axially per pass, inches.
NHS = No hardness specified.

TABLE 3.2-7

RIA Manufacturing Process Data Analysis Sheet for Broaching

Part No.	Operation	Material	SFM	Length of Cut	Feed Rate	Hardness	OTW
7793146	Broaching	8169	10	2.5	0.0005	33-36 R_c	G

Key: OTW = Observed tool wear mode.
SFM = Tool velocity, surface feet per minute.
Feedrate = Tool advancement rate, inches per minute.
G = Good

3.2.2 Severity Index Considerations

In order to achieve this goal, an overall severity index must be developed for RIA that will accomplish the following: define severity, be uncomplicated to calculate, and accurately describe RIA requirements.

Severity of a machining operation is usually considered to be a function of the level of difficulty associated with one or a combination of the parameters which describe it. For example, a turning operation's basic parameters are the speed, feed and depth of cut. In all the parameters, the higher the value the more difficult the operation. Also, each parameter must be compared to one another. In the case of turning, increasing the speed produces a more severe operation than increasing the feed; and increasing the feed produces a more severe operation than does increasing the depth of cut. These are the types of considerations taken in the development of the overall severity index.

The purpose of the preliminary severity analysis is twofold, first to establish the relative severity within a basic machining operation; secondly, to develop an overall severity index that will be used to compare all of the basic machining operations performed throughout Rock Island Arsenal. The development of the overall severity index, the index that can be related to all the basic machine operations, requires performing three separate tasks. These tasks are ranking the severity levels of the process parameters, developing a consistent scaling technique within these ranks, and extending the ranking to permit comparisons between different processes. The rationale followed for each of these tasks are described individually as follows:

1. Rank the Severity of the Critical Machining Process Variables

Each machining operation has process variables such as speed, feed, depth of cut, etc. These components are ranked on an interval scale from one to three, three being the most severe and one being the least. For example, below is how boring cutting speeds were ranked.

Rank	SFM
3	250 and above
2	100-249
1	0-99

All of the different observations of the basic machining operations being studied can then be ranked in this manner.

2. Develop a Scaling Technique to Define the Most Severe Operations of the Basic Machining Operation Being Evaluated

Establishing a quantitative ranking taking into account all the process variables whose rank was established in task one requires the development of a special technique. First, this technique involves assigning a coefficient of relative importance or weighting factors to each of the process variables rankings defined in Task 1.

Second, the summation of the products of the weighting factors times their related rank then provides a number representing the relative severity of the machine operation or observation in question. This logic is then applied to all of the observations of the basic machining operations being evaluated. The result is a representative ranking of the observations of the machining operations being studied. This ranking has been defined as the basic operation severity rank. The weighting factors must be chosen in a manner which will develop a representative spread of the severity of the operation. For example, the operation severity rank will be calculated for boring. First the ranking of each of the basic machining parameters for all the different parts observed as in Task 1 must be accomplished. This is displayed in Table 3.2-8. Next, weighting factors must be developed to take into account the relationship between SFM, feed rate, depth of cut, hardness and metal removal rate (MRR). Past experience has shown that increasing the SFM creates a more severe operation than an increase in feedrate. An increase in feedrate produces a more difficult operation than an increase in depth of cut. Material hardness also has a major influence on machinability. Three ranges of hardness can be established to rank material machinability. Workpieces below R_c28 are readily machined although the chips tend to be stringy and difficult to break. The range between R_c28 and R_c36 represents moderately difficult to machine steels. Alloys heat treated to hardnesses above R_c36 rapidly are more difficult to machine.

All of these considerations were taken into account in the development of the weighting factors displayed in Table 3.2-9 for the boring operation. Lastly, the summation of the products of the weighting factors with their associated rank number is calculated to form the basic operation severity rank. This operation is displayed below in detail for part number 5507239.

$$(R_{Speed} = 2)(WF_{Speed} = 3) \quad + \quad (R_{Doc} = 2)(WR_{Doc} = 1)$$

$$+ \quad (R_{Feed} = 2)(WF_{Feed} = 2) \quad + \quad (R_{Hardness} = 0)(WF_{Hardness} = 100)$$

$$+ \quad (MRR = 3.8)(WF_{MRR} = 17) \quad = \; 76.6 = \text{Basic Operation Severity Rank}$$

<u>Key:</u> R = Rank
WF = Weighting Factor
Doc = Depth of Cut

These calculations are continued for all the boring operation in Table 3.2-10.

TABLE 3.2-8

The Ranking of the Boring Machining Parameters

SFM	Depth of Cut(in.)	Feed Rate (In/Rev)	Hardness	MRR	OTW	Operation	Part No.
197 SFM Rank=2	0.125 Rank=2	0.013 Rank=2	NHS Rank=0	3.8	G	Bore ID	5507239
237 SFM Rank=2	0.125 Rank=2	0.015 Rank=3	R_c 26-32 Rank=0	5.3	-	Bore ID	8449307
294 SFM Rank=3	0.125 Rank=2	0.015 Rank=3	R_c 26-32 Rank=0	6.6	-	Bore ID	8449307
316 SFM Rank=3	0.060 Rank-1	0.015 Rank-3	R_c 26-32 Rank-0	3.4	-	Bore ID	8449307
221 SFM Rank=2	0.187 Rank=3	0.012 Rank-2	BHN 242 248 Rank=0	6.0	CH	Bore ID	6508898

Key: See Table 3.2-1

TABLE 3.2-9

Weighting Factors for Boring

Machining Parameter	Weighting Factor
SFM	3
Depth of Cut	1
Feed Rate	2
Hardness	100
MRR	17

TABLE 3.2-10

Sample Calculations for the Development of the Basic Operation Severity Index for Boring

Part No.	Weighting Factors Times Their Related Ranks					Basic Operation Severity Rank
	(SFM)	Depth of Cut	(Feed Rate)	(Hardness)	(MRR)	
5507239	[(R=2)x3] +	[(R=2)x1] +	[(R=2)x2] +	[(R=0)x100] +	(3.8x17)	= 76.6
8449307	[(R=2)x3] +	[(R=2)x1] +	[(R=3)x2] +	[(R=0)x100] +	(5.3x17)	= 104.1
8449307	[(R=3)x3] +	[(R=2)x1] +	[(R=3)x2] +	[(R=0)x100] +	(6.6x17)	= 129.2
8449307	[(R=3)x3] +	[(R=1)x1] +	[(R=3)x2] +	[(R=0)x100] +	(3.4x17)	= 73.8
6508898	[(R=2)x3] +	[(R=3)x1] +	[(R=2)x2] +	[(R=0)x100] +	(6.0x17)	= 115.0

From the above presentation it can be noted that the operation with the 129.2 severity rank is the most severe operation and the operation with the 73.8 severity rank the least.

3. Extrapolate the Basic Operation Severity Rank to an Overall Severity Index

The final step is to establish an index that will be used to compare the currently studied basic machining operations to all the machining operations within Rock Island Arsenal. Again, a one to three interval scale has been utilized. The highest value of the basic operation severity rank is given an overall severity index rank of three. The lowest is given an overall severity index of one. The previously discussed case of the boring was handled in a similar manner. All the values above 100 were given an overall severity ranking of three. All the values above 50 were given a two. Note, in this case, none of the values qualify for an overall severity rank of one.

3.2.3 Turning and Boring

The turning and boring operations may be divided into two basic groups; N/C (numerical control) and conventional. N/C turning contained the most severe operations. This was due to the high surface feed at which the equipment was operated, typically, 700 to 800 SFM. Also, the N/C equipment had larger motors and heavier frames that allowed for an increased depth of cut.

In general, most of the operations observed were run above Machinability Data Handbook standards. This was due to the excellent knowledge of the area foremen and the individual machine operators of how to fully utilize carbide cutting tools and to properly apply cutting fluids. The material hardness was characteristically below the R_c30 range. Most of the depths of cuts ranged from 0.100-0.250 inch. Typically, the feed rates ranged from 0.013 inch/revolution to 0.026 inch/revolution.

Each turning and boring operation was ranked for its severity in cutting speed, depth of cut, feed rate and hardness through the use of a one to three interval scale, three being the most severe and one being the least severe. Also, each turning and boring operation's metal removal rate was calculated and the mode of the observed tool wear was specified. The overall severity ranking was attributed to the combination of all these factors.

Establishment of a quantitative severity index required combining these five factors (tool wear mode was not used) in a logical manner. A weighting technique was developed which involved assigning a coefficient of relative importance to each of the five factors. Summation of the five products then provides a number representing the relative severity of the various RIA turning and boring operations. This number (the basic operation severity rank) was then converted back to a one to three interval scale which will be used to compare turning and boring to all the other machining operations. This last interval scale is called the overall severity index. The procedure is illustrated in Table 3.2-11 for turning and Table 3.2-12 for boring.

3.2.4 Drilling and Tapping

It was apparent from the analysis sheets that all drilling and tapping operations were conducted at common parameters. Most of the holes had aspect ratios in the 2-3 range with one exception. All tapping was performed at the same rates; hence, it was not necessary to develop individual indices, but a single value can be developed to describe the operations as they are currently performed.

TABLE 3.2-11

Summary Table for Turning Severity Index Determination

Overall Severity Index	SFM	Depth of Cut	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
Weighting Factors	3	1	2	100	6				
1	422 Rank=2	0.005 Rank=1	0.013 Rank=2	170-BHN 248 Rank=0	0.3	12.8	CH	NC Facing	8449036
3	781 Rank=3	0.140 Rank=2	0.026 Rank=3	170-BHN 248 Rank=0	34.1	221.6	CR	N/C Rough Turn OD	8449036
1	781 Rank=3	0.020 Rank=1	0.026 Rank=3	170-BHN 248 Rank=0	4.9	45.4	CR	N/C Finish Turn OD	8449036
2	413 Rank=2	0.150 Rank=2	0.014 Rank=2	R_c 25-30 Rank=0	10.4	74.4	CH	Turn OD with Ceramic	10891793
2+	413 Rank=2	0.150 Rank-2	0.014 Rank=2	R_c 29-36 Rank=1	10.4	174.4	CH	Turn OD with Ceramic	10956584
2	375 Rank=2	0.100 Rank=2	0.015 Rank=2	R_c 33-35 Rank=1	6.7	152.2	-	Turn OD	12007666
2	256 Rank=1	0.250 Rank=3	0.017 Rank=2	R_c 25-30 Rank=0	13.1	88.6	G	Turn OD	12007623
1	423 Rank=2	0.060 Rank=2	0.015 Rank=2	R_c 26-32 Rank=0	4.6	39.6	CR	Turn OD	8449307
3	848 Rank=3	0.140 Rank=2	0.026 Rank=3	R_c 26-32 Rank=0	37.0	239.0	-	N/C Turn OD	8382446
3	761 Rank=3	0.140 Rank=2	0.026 Rank=3	R_c 26-32 Rank=0	32.0	209.0	-	N/C Turn OD	8382446

TABLE 3.2-11 (continued)

Weighting Factors	3	1	2	100	6				
Overall Severity Index	SFM	Depth of Cut	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
2	411 Rank=2	0.140 Rank=2	0.018 Rank=2	R_c 20-25 Rank=0	12.4	86.4	-	N/C Turn OD	10895646
Ranking Criteria	500-UP=R=3 300-499= R=2 100-299= R=1	0.250-UP=R=3 0.060-0.244= R=2 0-0.059=R=1	0.026-UP= R=3 0.01-0.025= R=2 0-0.009= R=1	41-46=R=2 35-40=R=1 0-34=R=0		200-UP=R=3 50-199=R=2 0-49=R=1			

Key: See Table 3.2-1

TABLE 3.2-12

Summary Table for Boring Severity Index Determination

Overall Severity Index	SFM	Depth of Cut	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
Weighting Factors	3	1	2	100	17				
2	197 Rank = 2	0.125 Rank = 2	0.013 Rank = 2	NHS Rank = 0	3.8	76.6	G	Bore ID	5507239
3	237 Rank = 2	0.125 Rank = 2	0.015 Rank = 3	R_c 26-32 Rank = 0	5.3	104.1	-	Bore ID	8449307
3	294 Rank = 3	0.125 Rank = 2	0.015 Rank = 3	R_c 26-32 Rank = 0	6.6	129.2	-	Bore ID	8449307
2	316 Rank = 3	0.060 Rank = 1	0.015 Rank = 3	R_c 26-32 Rank = 0	3.4	73.8	-	Bore ID	8449307
3	221 Rank = 2	0.187 Rank = 3	0.012 Rank = 2	BHN 242 248 Rank = 0	6.0	115.0	CH	Bore ID	6508898
Ranking Criteria	250-UP=R=3 100-249= R=2 0-99=R=1	0.150-UP=R=3 0.100-0.144 =R=2 0-0.099 =R=1	0.015-UP =R=3 0.012-0.014 =R=2 0-0.013	40-45=R=10 35-40=R=1		100-UP=R=3 50-99=R=2 0-49=R=1			

Key: See Table 3.2-1

The data observed for those operations are presented in Table 3.2-4 for drilling and Table 3.2-5 for tapping. A tentative severity index was established by considering the surface speed, chip load, and aspect ratio. The index has been weighted such that a rank of two represents a high medium severity index and has been assigned a rank of two to be consistent with turning operations. Laboratory tests will be required later in this program to refine these data into an overall quantitative system for rating machining operations on a relative basis.

Tapping operations involve internal thread generation in which the depth of cut is directly proportional to the hole diameter for basically all threads. The tap speed, hole depth and whether through or blind holes are produced are the critical factors for incorporating into a severity index. An overall severity index of two was established for all the tapping operations observed.

3.2.5 Milling Operations

Milling operations at RIA can be placed in three basic categories: face, end, and peripheral milling. These operations are performed on either N/C or conventional machine tools. The N/C equipment was operated at speed ranges of 400-700 SFM, somewhat higher than the 100-350 SFM range of the conventional machines. Many of the face milling operations were performed without the use of a cutting fluid.

The milling operations were organized into three categories in order to define their severity index more accurately. These categories are face milling, end milling and conventional peripheral milling. Each of these utilize different tool geometries and have different parameter ranges which are presented in Tables 3.2-13 to 3.2-15.

The feed per tooth and the feed rates varied depending on the operation. The hardness, except for two cases, of all the operations observed, was less than $R_c 30$ which is easy to machine. The exceptions were given special considerations when their severity index was developed.

Each of the three categories of milling was separately ranked for its severity in speed, feed per tooth, feed rate and hardness through the use of a one to three interval scale, three being the most severe and one being the least severe. Also, each milling operation's metal removal rate was calculated and the mode of the observed tool wear was specified. The overall severity ranking was attributed to the combination of all of these factors.

Establishment of a quantitative severity index required combining these five factors (tool wear mode was not used) in a logical manner. A weighting technique was developed which involved assigning a coefficient of relative importance to each of the five factors. Summation of the five products then provides a number representing the relative severity of the various RIA milling operations. This number was then converted back to a one to three interval scale, three being the most severe and one the least. This procedure is illustrated in Tables 3.2-13 through 3.2-15.

TABLE 3.2-13

Summary Table for Face Milling Severity Index Determination

	SFM	Feed/Tooth (in.)	Feed Rate (in/min)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
Weighting Factors	3	1	2	200	2				
Overall Severity Index									
1	314 Rank=2	0.002 Rank=1	4-8 Rank=3	NHS Rank=0	60	133	CH	Face Milling N/C, Dry	8449309
3	702 Rank=3	0.003 Rank=2	12.5 Rank=3	R_c 25-30 Rank=0	316	649	-	Face Milling Dry	10884271
2	650 Rank=3	0.002 Rank=1	7.6 Rank=3	R_c 31-38 Rank=1	119	454	CH	Face Milling Dry	7793063
2	629 Rank=3	0.002 Rank=1	8.0 Rank-3	NHS Rank=0	121	258	CH	Face Milling N/C	8444309
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0=0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		500-UP=R=3 250-499=R=2 0-249=R=1			

Key: SFM = Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.
R = Rank

TABLE 3.2-14

Summary Table for End Milling Severity Index Determination

Weighting Factors	3	1	2	200	4				
Overall Severity Index	SFM	Feed/Tooth (in.)	Feed Rate (in/min)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
1	60 Rank=1	0.0015 Rank=1	1.5 Rank=1	NHS Rank=0	2	14	-	N/C End Milling	8447309
3	334 Rank=2	0.001 Rank=1	2.0 Rank=1	NHS Rank=0	40	169	-	N/C End Milling	8447309
2	62.4 Rank=1	0.008 Rank-3	2.0 Rank=1	NHS Rank=0	12	56	-	End Milling	7133213
1	32 Rank=1	0.004 Rank=2	2.0 Rank=1	NHS Rank=0	3	19	CH	End Milling	6532032
1	63 Rank=1	0.0016 Rank=1	3.0 Rank=2	NHS Rank=0	4	24	-	N/C End Milling	8441309
1	57 Rank=1	0.003 Rank-2	3.0 Rank=2	NHS Rank=0	6	33	-	End Milling Boring,N/C	8449300
1	64 Rank=1	0.001 Rank=1	6.0 Rank=2	NHS Rank=0	5	28	-	End Milling Boring,N/C	8449300
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0..005-UP=R=3 0.003-0.0049 =R=2 0.0.0029=R-1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		150-UP=R=3 50-149=R=2 0-49=R=1			

Key: See Table 3.2-13

TABLE 3.2-15

Summary Table for Conventional Peripheral Milling Severity Index Determination

Weighting FActors	3	1	2	200	2				
Overall Severity Index	SFM	Feed/Tooth (in.)	Feed Rate (in/min)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
2	314 Rank=2	0.005-0.008 Rank=3	3-5 Rank=2	NHS Rank=0	150	313	-	N/C Slot Milling	8449309
3	398 Rank=2	0.004-0.007 Rank=3	5-8 Rank=3	NHS Rank=0	267	549	CH	N/C Slide Milling	8449309
1	314 Rank=2	0.003-0.004 Rank=2	3-4 Rank=2	NHS Rank=0	53	118	CH	N/C Side Milling	8449309
2	47 Rank=1	0.005 Rank=3	2.63 Rank=1	R_c 42-46 Rank-2	7	422	-	Peripheral Milling	7791379
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0=0.0029=R=1	7-UP=R=3 3.6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		500-UP=R=3 250-499=R=2 0-249=R=1			

Key: See Table 3.2-13

3.2.6 Grinding Operations

Grinding requirements for Rock Island Arsenal are somewhat different from most commonly encountered grinding operations. Grinding is typically used to machine hard or difficult to machine parts where other types of machining processes cannot be utilized. The unique feature at Rock Island is that the bulk of the material being ground is unhardened 4100 series steels. The surfaces being ground are most commonly wear surfaces which must be ground to specific surface finishes to provide for adequate film lubrication during service, or to provide a sufficiently qualified surface for subsequent chrome plating. The chrome plating is used to provide superior wear resistance during service. Several production grinding operations were examined. These operations were done either on cylindrical or surface grinders and are presented in Table 3.2-6.

The major observation is that all current grinding operations may be grouped into a single severity index category. However, since the grinding speeds are an order of magnitude higher than milling and the effective tool geometries involve highly negative rake angles, a special severity index will have to be established to adequately treat the grinding process requirements. Tests are currently in progress to establish these requirements and will be incorporated in the Phase II program effort.

Observations regarding grinding equipment at Rock Island Arsenal were made and may be summarized by the following:

1. Spindle speeds are governed by constant speed AC motors. Thus the actual surface speeds of the wheels decrease as the wheel radius decreases during use.

2. Infeeds are, in general, 0.001 inch for roughing operations and 0.005 inch for finishing operations. These values can be attributed to limitations imposed by the flexibility of the parts being ground. Any larger infeed values would cause excessive part deflection creating tolerance problems.

3. On cylindrical parts, the cross feeds are larger than those normally found in the Machinability Data Handbook. This would tend to load the part being ground in the axial direction, the direction in which the part is most rigid. The metal removal rates can then be increased without sacrificing tolerance.

4. For the surface grinding operations observed, the wheels were six inches in width. A large crossfeed could be used while producing a good finish with these wide wheels.

5. Specific levels of cross feed were found to be subject to considerable variation. Machine operators were free to select parameters on an individual basis to meet surface finish and size requirements.

6. Dressing was infrequently done as compared to most operations involving intricate forms or difficult-to-grind high temperature alloys. In most cases, dressing was done once every hour and was primarily required to remove wheel loading.

7. Relative to the previous observation, Cimfree 238 used at concentrations of approximately 100:1 is inadequate to prevent wheel load, but prior attempts to use this product at richer concentrations has resulted in reports of operator problems. The lean concentration is also somewhat inadequate to prevent rusting of machines, fixtures, and occasionally workpieces.

3.2.7 Broaching Operations

Broaching is typically a low speed cutting operation used for the generation of various two dimensional forms. Because of the low speeds involved, the most commonly experienced type of tool wear is of the built-up-edge type. A cutting fluid for these operations should have excellent lubricating properties with adequate E.P. additives.

There was only one broaching operation in production during visits to the Arsenal. This operation consisted of producing the rifling internally in 50 caliber machine gun barrels. The fluid was applied at 300 psi through a collet where the broach entered the part. Poly-Form Oil's Topaz 7/100 oil was used for the operation and seemed to perform adequately. Parts were inspected 100% for tearing in the as-cut surface. As soon as tearing was evident, the broach tool was sent to the tool room for resharpening.

No severity index was developed for broaching at this time. All of the broaching observed was for the 50 caliber machine gun barrels, part number 7793146. The following data are typical for this operation:

SFM:	10 ft/min
Length of Cut:	2.5 ft
Rise/Tooth:	0.0005 inch
Total Depth of Cut:	0.010 inch lands
	0.050 inch grooves

Later in the program, an index will be established which characterizes the special requirements for broaching. The most likely results will be that a fortified oil will be required to maintain part surface integrity for a longer period of tool life and to minimize present wear rates on the broach tools.

3.2.8 Future Uses of the Severity Index

By following the procedures described in the preceding subsections, a severity index could be calculated for any new machining operation that the Arsenal may be required to perform. This index may be used as a planning or cost estimating tool. Fill in the blank type severity index forms are provided in Appendix A. A sample form for boring is displayed in Figure 3.2-1. For example, a new part has to be bored having the following machining parameters: Part Number: 7771777, SFM: 255 D.O.C. = .125, Feed: .015, Hardness = 32 Rc. First, the initial data is filled in on the form (see Figure 3.2-2). Second, the metal removal rate is calculated (12"/ft x 255 SFM) (.125") (.015"/rev) = 5.74.

Boring Severity Index Determination Table

Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
Weighting Factors	3	1	2	100	17				
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
Ranking Criteria	250-UP=R=3 100-249= R=2 0-99=R=1	0.150-UP=R=3 0.100-0.144 =R=2 0-0.099 =R=1	0.015-UP =R=3 0.012-0.014 =R=2 0.0.013 =R=1	40-45=R=10 35-40=R=1		100-UP=R=3 50-99=R=2 0-49=R=1			

Key: SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.

MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.

Figure 3.2-1 Sample Severity Index Determination Sheet.

Boring Severity Index Determination Table

Weighting Factors	3	1	2	100	17				
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	255	.125	.015	32 Rc					
	Rank = 3	Rank = 2	Rank = 3	Rank = 0	5.74	113.9		Bore ID	7771777
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
Ranking Criteria	250-UP=R=3 100-249= R=2 0-99=R=1	0.150-UP=R=3 0.100-0.144 =R=2 0-0.099 =R=1	0.015-UP =R=3 0.012-0.014 =R=2 0.0.013 =R=1	40-45=R=10 35-40=R=1		100-UP=R=3 50-99=R=2 0-49=R=1			

Key: SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.

MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.

Figure 3.2-2 An Example of How to Use the Severity Index Determination Table.

Next, the basic operation severity rank must be calculated. In order to accomplish this each machining parameter must be ranked. The ranking value is determined by comparing the parameter value to the chart at the bottom of the parameter's column. In the case of SFM, the rank for 255 SFM would be 3 (see Figure 3.2-2). Once the ranks are calculated, the summation of the products of the weighting factor with their associated rank number is calculated to form the basic operation severity rank. This operation is displayed below in detail for this example:

$$(R_{Speed} = 3)(WF_{Speed} = 3) + (R_{Doc} = 2)(WF_{Doc} = 1)$$

$$+(R_{Feed} = 3)(WF_{Feed} = 2) + (R_{Hardness} = 0)(WF_{Hardness} = 100)$$

$$+(MRR = 5.7)(WF_{MRR} = 17) = 113.9 = \text{Basic Operation Severity Rank}$$

Key: R = Rank
WF = Weighting Factor
Doc = Depth of Cut

The final step is to calculate the overall severity index. At the bottom of the column of the basic operation severity rank is the table of values used to determine this value. For our example the overall severity rank should be 3. A considerable amount of discussion preceded selection of three basic severity index ranges. It was felt that a larger number of range intervals would defeat the basic purpose of this program, to simplify fluid selection procedures.

3.3 Cutting Fluid Manufacturer Survey and Test Fluid Selection Criteria

In general, experience has shown most manufacturing facilities have not given cutting fluids the priority they should receive. This portion of the report will provide some background on cutting fluids and emphasize their importance in the manufacturing process. It will look at the different types of fluids available, their basic composition, and discuss criteria for testing. The purpose of this section is to describe the types of cutting fluids available, the benefits of each type, and criteria for cutting fluid selection.

3.3.1 Cutting Fluid Manufacturer Survey

The total of 19 cutting fluid manufacturers and 65 cutting fluids has been included in the program evaluation. These manufacturers and associated cutting fluids are first displayed in Table 3.3-1. This table has the fluids divided into general categories often associated with cutting fluids: heavy duty, medium duty and light duty. These general categories were developed from information supplied by manufacturers. However, this table subdivides these general categories into the specific types of cutting fluids

TABLE 3.3-1

Candidate Cutting Fluids Categorized by Type and Manufacturer's Listed Application

	Neat Oil	Water Soluble	Semi-Synthetic	Synthetic
HEAVY DUTY	Do-All Co. No. 240 Econ. Lab Magnus Div. CB-66 Gulf Oil Gulfcut 21D Mobil Oil Mobilmet Gamma Poly-Form Oils Topaz 7/100 Sun Petroleum Prod. Sunicut 352 Valvoline Oil 1023 1455S Van Straaten 5299 Series	Cincinnati Milacron Cimperial 1011 Do-All Power-Cut 390 EHD Econ. Lab Magnus Div. EP Coolant Gulf Oil Gulfcut Heavy Duty International Refining Irmco 335 Master Chemical Trim RD2-83A Trim Sol Norton Wheelmate 811 Stuart SOLVOL 6633 DASCO 1149 CODOL 0748 Valvoline Oil ADSOLI ADSOL3 Van Straaten 768	Fremont 7036 Norton Co. Wheelmate 674	Cincinnati Milacron Cimfree 238 Econ. Lab Magnus Div. MX5080 SYN LOGO HD Fremont 7012 Master Chemical Trim 9106-CS Stuart DAS COOL 4408B Valvoline Oil ADCOOL 3 Van Straaten 951
MEDIUM DUTY	Econ. Lab Magnus Div. CC-6 Gulf Oil Gulfcut 11D Mobil Oil MobilMet Sigma Valvoline Oil 1002 1401	Econ. Lab Magnus Div. Magna-Cool 60 Gulf Oil Gulfcut Soluble International Refining Irmco 303 Mobil Oil MobilMet S-125 Ohio Industrial Res. Mastercut Stuart DASCO 1086 Sun Petroleum Prod. Emulsun 51 Valvoline Oil ADSOL 2 E. F. Houghton & Co. Hocut 3210-X	Cincinnati Milacron Cimcool Five Star 40 Freemont 7030 E. F. Houghton & Co. Hocut 711 Johnson Wax JON-COOL 800 Stuart DASCOOL 502 Aluminum DASCOOL 4379 Van Straaten 550-P Wynn Oil Co. Semicool 969	Do-All Co. Power Cut HD-600 Fremont 7011 E. F. Houghton & Co. Hydra-Cut 496 International Refining Irmco 103 Norton Co. Wheelmate 689 Poly-form Oils Poly Aqua Stuart DASCOOL 427 Tapmatic ME II Valvoline Oil ADCOOL 2 Wynn Oil Co. 951-1 Synthetic 941 Synthetic
LIGHT DUTY	Econ. Lab Magnus Div. DO-5A	Do-All Co. 470 Mobil Oil MobilMet 140		Fremont 7013

892-0

marketed today which are: neat oils, water soluble oils, semi-synthetic fluids and synthetic fluids. Two of the questions often asked about cutting fluids are:

1. What type of cutting fluid works on which machining process?

2. How do the various costs of the different types of cutting fluids compare?

Table 3.3-2 is a first step in answering these questions. This table lists all the candidate cutting fluids and indicates what machining operations the manufacturers recommend they may be used in. A blank space indicates the fluid is not generally used for that application. This table also specifies the dilution ratio of water to cutting fluid concentrate (fluid concentration) for the specified machining operation and how much it costs to fill a 50 gallon sump at the recommended concentration. Each rectangle is divided into two portions: the top portion contains the dilution ratio (i.e., 19:1) and the bottom half displays the cost to fill a 50 gallon sump.

These data are presented to indicate how important it is to compare the COST PER DILUTED GALLON of a cutting fluid, not just the cost of the fluid concentrate. Also, this table indicates the quantity of products available that can be used on the majority of machining operations at RIA.

Telephone interviews were held with all the manufacturers included in the program. In all cases, technical data describing the fluids were requested and sample quantities of many products were obtained for evaluation. The two questionaires used to obtain technical information for neat oil cutting fluids and cutting fluids diluted in water are displayed in Figures 3.3-1 and 3.3-2.

Five on-site interviews were conducted; these included:

Lubrizol, Cleveland, Ohio;
D. A. Stuart Oil Co. of America, Willowbrook, Illinois;
Economic Laboratories, St. Paul, Minnesota;
Cincinnati Milacron, Cincinnati, Ohio; and
Master Chemical Corporation, Perrysburg, Ohio

Also, the Polyform Oils Company and the Valvoline Oil Company sent their head chemists to discuss the chemical properties and advantages of their products. The products discussed represented essentially all classes of formulations and were designed for a variety of applications. The discussions, however, revealed a strong thread of commonality. Virtually all the suppliers stresses two important aspects of cutting fluid application technology, concentration and contamination.

One of these major considerations in the successful application of cutting fluid is to initially dilute the products to the proper concentration specified. This concentration must then be maintained throughout the life of the product in the fluid delivery system. There are four major types of additives in a soluble cutting fluid: extreme pressure (E.P.) additives or lubricants, rust preventatives, mold controllers and

TABLE 3.3-2. CUTTING FLUID MANUFACTURER INFORMATION

Manufacturer	Product	Neat Oil		Water Soluble Oil							Semi-Synthetic Fluid							Synthetic Fluid						
		Broaching	Boring	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching
Cin. Milacron	Cimperial 1011			20:1 / 16.47	20:1	20:1	20:1		20:1	20:1														
FOB Cincinnati	Cimcool Five Star 40										25:1 / 11.00	25:1	25:1	25:1		25:1	25:1							
	Cimfree 238																	25:1 / 12.50	25:1	25:1	25:1		25:1	25:1
DOALL Company	Power-Cut 390 EHD			20:1 / 21.43	20:1	20:1	20:1		40:1 / 10.71	5:1 / 75.0														
(delivered)	" HD-600																	15:1 / 24.38	15:1	15:1	15:1			
	No. 470 Soluble Oil			10:1 / 18.41	10:1	10:1	10:1																	
	No. 240 Cutting Oil	X / 334.50	X																					
Fremont Ind.	7011																	30:1 / 10.68	30:1	40:1 / 8.07	40:1		60:1 / 5.43	20:1 / 15.76
	7012																	30:1 / 10.89	30:1	40:1 / 8.23	40:1		60:1 / 5.53	20:1 / 16.07
	7013																	30:1 / 11.63	30:1	30:1	30:1		40:1 / 8.79	
	7030										40:1 / 8.73	40:1	40:1	40:1		50:1 / 7.02	20:1 / 17.05							
	7036										40:1 / 9.10	40:1	40:1	40:1			20:1 / 17.76							
Gulf Oil Corp.	Gulfcut Hvy. Duty Soluble			20:1 / 8.50	15:1 / 11.16	15:1	15:1																	
(deliv.) Use for Aluminum	Gulfcut 110																							
	Gulfcut 210	X / 118.44	X																					
Use for Aluminum	" Solub.																							
E.F.Houghton&Co.	Hocut 711										25:1 / 8.21	30:1 / 6.89	25:1	25:1										
	Hydracut 496																	25:1 / 12.40	25:1	25:1	25:1			
	Hocut3210-X			25:1 / 13.46	30:1 / 11.29	35:1 / 9.72	35:1																	
International Ref.	Irmco 103																	25:1 / 10.10	25:1	15:1 / 16.41	15:1		30:1 / 8.47	10:1 / 23.86
	" 303			25:1 / 12.21	30:1 / 10.24	15:1 / 19.14	15:1		40:1 / 7.75	10:1 / 28.86														
	" 335			40:1 / 10.37	40:1	15:1 / 26.64	15:1		40:1 / 10.37	8:1 / 47.32														
Johnson Wax FOB Iowa	Jon-Cool800										30:1 / 11.21	30:1	30:1	30:1		30:1	30:1							

Key: Dilution Ratio / Cost to Fill a 50 Gal. Sump

895-D

TABLE 3.3-2. CUTTING FLUID MANUFACTURER INFORMATION

Manufacturer	Product	Neat Oil		Water Soluble Oil							Semi-Synthetic Fluid							Synthetic Fluid						
		Broaching	Boring	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching
Magnus Div. Econ. Lab.	Magnacool 60								40:1 / 7.18															
	MX 5080																	30:1 / 26.27	30:1	20:1 / 38.79	20:1		40:1 / 19.87	10:1 / 74.05
	SYN LOGO HD																	30:1 / 17.73	30:1	20:1 / 36.16	20:1		40:1 / 13.40	
	EP Coolant			20:1 / 16.19	20:1	15:1 / 21.25	15:1		40:1 / 8.29	10:1 / 30.90														
Use for Aluminum	DO-5A		GRIND / 264																					
	CC-6	X / 260.32	X																					
	CB-66	X / 517.72	X																					
Master Chemical	Trim Sol			19:1 / 17.25	19:1	19:1	19:1		19:1	9:1 / 34.50														
FOB Perrysburg, Ohio	Trim9106CS																						24:1 / 13.20	
	TrimRD2-83A									7:1 / 67.19														
Mobil Oil Corp.	Mobilmet 140			20:1 / 7.60	20:1	20:1	20:1		20:1															
(delivered)	" S-125			15:1 / 11.53	15:1	15:1	15:1		15:1	15:1														
	" Sigma		X / 116.00																					
	" Gamma	X / 119.50	X																					
Norton Co.	Wheelmate 689																	20:1 / 17.23	20:1	20:1	20:1		20:1	20:1
	" 811			20:1 / 21.00	20:1	20:1	20:1		20:1	20:1														
	" 674										20:1 / 16.50	20:1	20:1	20:1		20:1	20:1							
Ohio Industrial Research	Mastercut			20:1 / 10.67	20:1	20:1	20:1		40:1 / 5.46	10:1 / 20.34														
Poly-Form Oils FOB Anaheim, CA	Poly-Aqua																	25:1 / 9.52	25:1	25:1	25:1		30:1 / 7.98	10:1 / 22.50
FOB Rockfd., IL	Topaz-7/100	X / 180.50	X																					
D.A. Stuart Oil	Dascool 427																	30:1 / 12.50	30:1	30:1	30:1		35:1 / 10.76	
	" 502										25:1 / 14.42	25:1	25:1	25:1		30:1 / 7.82								
	" 4379										25:1 / 8.46	25:1	25:1	25:1										
	" 4408B																	20:1 / 13.05	20:1	20:1	20:1			
	" 1086			25:1 / 7.27	25:1	25:1	25:1		30:1 / 6.10															

Key: Dilution Ratio / Cost to Fill a 50 Gal. Sump

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TABLE 3.3-2. CUTTING FLUID MANUFACTURER INFORMATION

Manufacturer	Product	Neat Oil		Water Soluble Oil							Semi-Synthetic Fluid							Synthetic Fluid						
		Broaching	Boring	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching	Turning	Milling	Boring	Drilling	Tapping	Grinding	Broaching
	" 1149			25:1 / 11.25	20:1 / 13.93	25:1	25:1		30:1 / 9.44															
	Codol 0748			25:1 / 10.10	20:1 / 12.50	25:1	25:1		30:1 / 8.47															
	Solvol6633			25:1 / 9.46	25:1	30:1 / 7.94	30:1																	
Sun Petroleum Pr	Emulsun 51			20:1 / 7.76	20:1	20:1	20:1		40:1 / 3.98	10:1 / 14.81														
FOB Chicago	Sunicut 352		X / 163.00																					
Tapmatic Corp. FOB Irvine, CA	ME II Super Concentra.																	40:1 / 20.12	40:1	40:1	40:1		80:1 / 10.19	10:1 / 75.00
Valvoline	ADSOL 2			20:1 / 10.74	20:1	10:1 / 20.50	10:1	10:1	40:1 / 5.50															
FOB Findlay, OH	" 3			25:1 / 10.79	25:1	10:1 / 25.50	10:1	10:1	50:1 / 5.50	5:1 / 46.75														
	ADCOOL 2																	20:1 / 10.65	20:1	5:1 / 37.28	5:1		40:1 / 5.46	5:1 / 36.91
	" 3																	20:1 / 17.69	20:1	10:1 / 35.38	10:1		50:1 / 7.28	5:1 / 61.91
Van Straaten Chem	951																	10:1 / 21.18	10:1	10:1	10:1		20:1 / 11.10	10:1 / 21.18
FOB North ~~Aurora, IL~~	768			10:1 / 26.86	10:1	10:1	10:1		20:1 / 14.02	10:1 / 26.86														
	5299	X / 161.50	X / 161.50																					
	550-P										25:1 / 9.83	25:1	25:1	25:1		35:1 / 6.74								
Wynn Oil Co.	951-1 Synthetic																	25:1 / 12.38	10:1 / 29.24	10:1	10:1		50:1 / 6.31	10:1
	941 "																	20:1 / 10.50	10:1 / 20.04	10:1	10:1		30:1 / 7.11	7:1 / 27.55
	Semicool969										9:1 / 32.22	9:1	9:1	9:1		49:1 / 6.44								

Dilution Ratio / Cost to Fill a 50 Gal. Sump

FLUID CHARACTERIZATION QUESTIONNAIRE
FOR NEAT OIL PRODUCTS

Company Name: ______________________________ Fluid Name: ____________________

1. What is the type of base oil? ____

2. Describe the physical characteristics:

   Viscosity ____________________ Color ____________________

   Flash Point ____________________ Fire Point ____________________

3. Which of the following additive types are in the product:

   ________ Sulfur ________ Fatty Acids

   ________ Bromine ________ Phosphorous

   ________ Others ______________________________

   ____

4. Indicate which machining operations and materials that can be used with this product. (Leaving a blank space will indicate the fluid is not applicable.)

Operation	4100 Steel HSS	4100 Steel Carbide	6000 Aluminum HSS	6000 Aluminum Carbide
Turning	______	______	______	______
Milling	______	______	______	______
Grinding	______	______	______	______
Drilling	______	______	______	______
Broaching	______	______	______	______

5. How strong an odor does this fluid have?

   ________ None ________ Weak ________ Medium ________ Strong

6. Will this product have any of the following effects on equipment?

	None	Slight	Strong
Paint	______	______	______
Rust Inhibition	______	______	______
Lubricants	______	______	______
Stain Tools/Work Pieces	______	______	______
Misting	______	______	______
Foaming	______	______	______

7. What procedure must be taken to dispose of this product?

____

____

____

Figure 3.3-1 Data Collection Questionnaire Used for Neat Oil Products.

8. Is it economically feasible to recycle this product:

_______ Yes _______ No

9. Describe the recommended concentration testing method.

____

____

____

10. Are there additive replenishment packages available for this product?

_______ yes _______ No

11. What is the cost and delivery time of this product?*

	Break Point	Drum	Tank Wagon	Tank Car
	Gallons	____to____	____to____	____to____
1	Cost/Gal	________	________	________
	Delivery Time	________	________	________
	Gallons	____to____	____to____	____to____
2	Cost/Gal	________	________	________
	Delivery Time	________	________	________
	Gallons	____to____	____to____	____to____
3	Cost/Gal	________	________	________
	Delivery Time	________	________	________
	Gallons	____to____	____to____	____to____
4	Cost/Gal	________	________	________
	Delivery Time	________	________	________

* Available current price listings and delivery schedules may be provided.

Figure 3.3-1 (continued)

FLUID CHARACTERIZATION QUESTIONNAIRE
FOR PRODUCTS DILUTED IN WATER

Company Name: ______________________ Fluid Name: __________

1. Choose Generic Type: ________ Emulsion

________ Synthetic

________ Other ______________________

2. What are the dilution ratios for the following machining operations using 4100 steel and 6000 aluminum? (Leaving a blank space will indicate the fluid is not applicable.)

Operation	4100 Steel HSS	4100 Steel Carbide	6000 Aluminum HSS	6000 Aluminum Carbide
Turning	______	______	______	______
Milling	______	______	______	______
Grinding	______	______	______	______
Drilling	______	______	______	______
Broaching	______	______	______	______

3. Are there special mixing requirements?

________ None ________ Premix ________ Other ______________________

____

4. To what degree will any of the following factors affect the stability of the emulsion?

	No Effect	Medium Effect	Strong Effect
Temperature	______	______	______
Bacteria	______	______	______
Chip Material	______	______	______

5. Which of the following additive types are in the product?

________ Sulfur ________ Phosphorous

________ Bromine ________ Anti-rust

________ Oils ________ Anti-foam

________ Others ______________________

____

6. What color is this product? ______________________

7. How strong an odor does this product have as mixed?

________ None ________ Weak ________ Medium ________ Strong

Figure 3.3-2 Data Collection Questionnaire Used for Products Diluted in Water.

8. Will this fluid have any of the following effects on equipment?

	None	Slight	Strong
Paint	______	______	______
Rust Inhibition	______	______	______
Lubricants	______	______	______
Stain Tools/Work Pieces	______	______	______
Misting	______	______	______
Foaming	______	______	______

9. Are there additive replenishment packages available for this product?

______ Yes ______ No

10. What procedure must be taken to dispose of this product into a waste treatment system?

____

____

____

11. Describe the recommended concentration testing method.

____

____

____

12. What is the cost and delivery time of this product?*

Break Point		Drum	Tank Wagon	Tank Car
	Gallons	____ to ____	____ to ____	____ to ____
1	Cost/Gal	______	______	______
	Delivery Time	______	______	______
	Gallons	____ to ____	____ to ____	____ to ____
2	Cost/Gal	______	______	______
	Delivery Time	______	______	______
	Gallons	____ to ____	____ to ____	____ to ____
3	Cost/Gal	______	______	______
	Delivery Time	______	______	______
	Gallons	____ to ____	____ to ____	____ to ____
4	Cost/Gal	______	______	______
	Delivery Time	______	______	______

* Available current price listings and delivery schedules may be provided.

Figure 3.3-2 (continued)

agents for bacteria control. Other additives include emulsifiers, dyes and scenting chemicals. If any of the major constitutents are allowed to decrease in concentration, the fluid can lose its effectiveness. Loss or consumption of the emulsifiers, rust preventatives, mold controllers or bactericides can also result in fluid failures.

It was stressed by all suppliers that fluids should be mixed using a positive displacement pump rather than a Venturi-type mixing system. This recommendation was made because most experiences with Venturi-type systems have shown them to be subject to inconsistencies due to water pressure variations and plumbing flow rate differences. Further, crude concentration checks can be made with a refractomer if a refractive index vs. concentration chart has been specifically calibrated using laboratory analysis procedures, usually titration. Refractometers can be subject to serious error in cases where significant hydraulic fluid contamination is present. The refractometer cannot distinguish between the intentionally added fortified oil lubricants and the hydraulic oil contamination. Titration techniques are necessary to maintain fluid concentration levels if the hydraulic leakage problem cannot be controlled.

The second major consideration is the impact of tramp oil on soluble cutting fluid stability. Soluble emulsions and semi-synthetics are seriously affected by tramp oils. True synthetics are less seriously affected because they are true solutions and are inherently immiscible with oils.

The emulsifiers present in a soluble oil product are necessary to maintain product stability and maintain the fortified oil base lubricating phase dispersed in the water carrier. This dispersion is maintained by the special properties of the surfactant, or emulsifying agent. The surfactant can be viewed as an elongated molecule, one end of which is water-seeking or hydrophyllic while the other end is oil-seeking or lipophyllic. The structure of a nonionic surfactant is illustrated in Figure 3.3-3a. These molecules are selectively attracted to the interface between the water and oil phases. When the mixture is highly agitated, the oil is dispersed in the form of tiny droplets on the order of a micron or smaller in diameter. The surfactant remains at the oil/water interface and prevents recoalescence of the oil phase. The electrochemical charge on the surface of these droplets maintains the dispersion and the resulting product is a stable emulsion of oil in water (see Figure 3.3-3b).

Addition of tramp oil, characteristically by leakage from machine hydraulic systems, eventually results in failure of this stable dispersion. The emulsifiers present originally in the cutting fluid cannot distinguish between a droplet of the intentionally present fortified cutting oil and those composed of tramp oil. When tramp oil enters the emulsion, some of the emulsifiers leave their oil droplet in an attempt to emulsify the new tramp oil. When a new state of equilibrium is reached, the tramp oil droplet will also have surfactant molecules encircling it (see Figure 3.3-3c).

As more tramp oil is added to the emulsion, a saturation point is reached where the current ratio of surfactant to oil is reduced below the point where the current size oil droplets cannot be maintained and large size oil droplets are formed (see Figure 3.3-3d). This continues as more and more tramp oil is absorbed into the sump until a point where no more oil can be contained and an emulsion failure occurs. The oil found

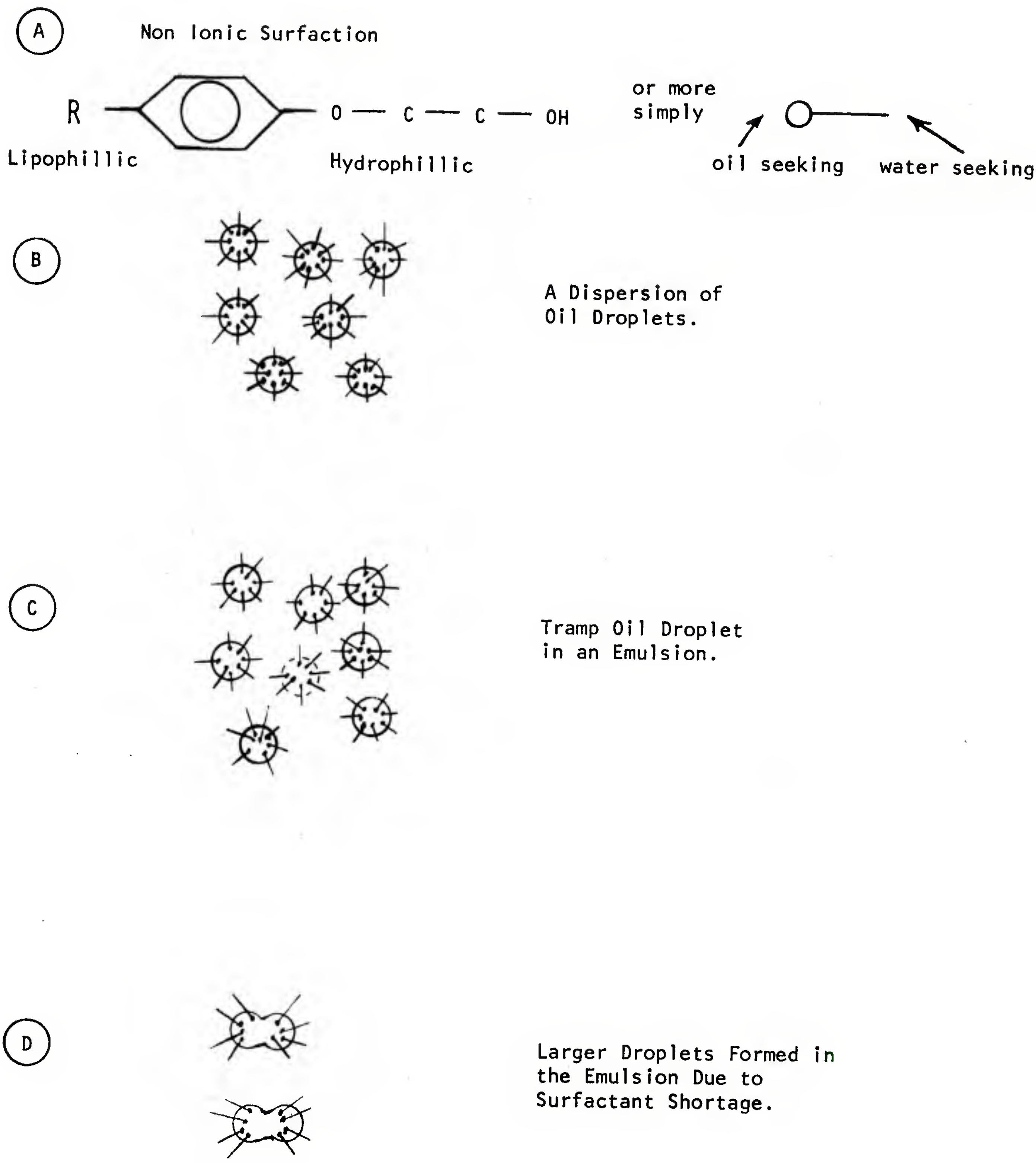


Figure 3.3-3. An Illustration of a non ionic Emulsion and how Tramp Oil will React with it.

floating on the sump is the result of this condition and may contain both the contaminating hydraulic fluid as well as the desirable cutting oil phase. This situation reduces the effectiveness of the product as a cutting fluid and eventually totally destroys the product, necessitating its replacement. This results in an unnecessarily premature removal of the fluid with its attendant replacement and disposal costs, but replacing hydraulic oils on the machines also represents a growing cost factor.

Synthetic fluids, being immiscible with oils, are subject to lesser degrees of damage. The major problem here is that oil separators are necessary to prevent displacement of the synthetic product in the sumps. Bacteria growth at oil/fluid interfaces is also encouraged if oil separation procedures are not utilized.

3.3.2 Initial Screening Tests

A program to technically evaluate all available present and future cutting fluids would be a virtual impossibility. Therefore, methods were developed to reduce the number of fluids to be tested. Three tests were conducted on all the fluids made available for initial screening: rust tests, bacteria tests and residue tests.

Rust Test:

The ability of a cutting fluid to inhibit the formation of rust is very important. Equipment efficiency will be reduced if they contained a cutting fluid that would allow rusting to occur. Also, rust prevention is very important for tooling and fixtures. Therefore, the initial criteria of a cutting fluid would be its ability to inhibit rust.

The rust test was conducted by putting 10 grams of freshly drilled cast iron chips on a piece of filter paper placed in a petri dish. Then 10 ml of cutting fluid mixed to the manufacturer's turning dilution ratio was poured over the chips. The test lasted one week. However, the fluids that did allow rusting usually did so in a few hours. The fluids that did not pass the rust test are:

Cimperial 1011, Cincinnati Milacron

Irmco 103, International Chemical Co.

Wheelmate 811, Norton Company

Poly Aqua, Poly-Form Oils

911, Wynn Oil Company

1149, D. A. Stuart Oil Company

Bacteria Test

Observations at RIA indicated the number one cutting fluid problem was anerobic bacteria growth. Each test fluid was tested for its ability to resist bacteria.

Fifteen ml of the test fluid mixed to the turning dilution ratio specified by the fluid manufacturers was inoculated with one drop of spoiled cutting fluid secured from

RIA. This screening test gave no results after a two-week incubation period at room temperature. This indicated that each test fluid contained a sufficient quantity of biocide to control a minimal amount of bacteria contamination. However, this is not representative of what may occur with daily recontamination.

Residue Test:

Another important property of a cutting fluid is what form of residue may be left behind after the water evaporates from it. Heavy or waxy residues could inhibit machine motions or if it forms hard crystalline deposits machine operation can score delicate wear surfaces.

Ten milliliters of test fluid mixed to the turning dilution ratio specified by the fluid manufacturers was allowed to stand at room temperature for one week. The only fluids that were questionable were Master Chemicals full synthetic 9106CS and Poly Form Oils Poly Aqua that left a salty residue. The rest of the test fluids left either a mildly gummy or an oily residue. The gumminess of the residues was judged not to be extremely objectionable. These tests resulted in elimination of six fluids from testing.

3.3.3 Criteria for Final Fluid Selection

Two factors were kept in mind when analyzing the various machining operations: the need for cooling and the need for lubrication. A high temperature machining operation such as grinding requires more cooling than lubrication. Milling, which is a lower temperature operation, requires more lubrication properties. However, some high temperature operations will experience a decrease in temperature if a lubrication additive is utilized. When such conditions exist, careful process analysis is required before a cutting fluid is selected.

Cooling is the ability of the cutting fluid to draw heat from the tool workpiece and chip. Lubrication is a property the cutting fluid has which allows it to produce a thin film between the tool/workpiece interface and tool/chip interface. This film reduces the friction between these surfaces and reduces the work required to accomplish the operation which reduces the heat generated. More specifically, it reduces the length of the cutting shear plane.

The state of the art of cutting fluid lubrication has advanced substantially in the last few years. Initially, natural oils and animal fats were used for lubrication. Currently, extreme pressure (E.P.) additives have come into wide use. An E.P. additive will break down and form a thin film layer at selective temperatures, depending on the additive, which will increase the lubrication capability of the oil on synthetics in the cutting fluid. Different types of E.P. additives perform different and in some cases when combined together will produce a synegestic effect and fluid performance will increase at a higher rate than the sum of that produced individually.

Initially, a possible fluid selection matrix was designed. Each basic machining operation was coupled with the four types of cutting fluids: full synthetics, semi-synthetics, emulsions and neat oils. Then as the machining severity index was developed, this initial matrix was reduced to the one exhibited in Table 3.3-3. Each fluid type was matched to RIA's machining operations. The major difficulty after this point was selecting which fluids would be actually tested. A computer program was designed to group all of the fluids by general type and then by chemical composition. Other pertinent data, such as mixability, effects on equipment paint, ease of waste disposal, foaming, and cost to fill a 50 gallon sump, were displayed on the computer printout (see Table 3.3-4). These data were used to select the test fluids. The exact logic is as follows:

1. Grouped All Fluids

Each cutting fluid was grouped by generic type and then by degree of fortification. Based on knowledge of its chemical composition, all cutting fluids in each strength category with similar additives were assumed to perform the same as other fluids of the same generic type and strength.

2. Selected Fluids From Each Generic Type

Each machining test contained fluids from each generic type and strength categories applicable, as dictated by the machining severity index.

3. Performed Special Tests

After one fluid from each generic type was tested, special tests were conducted initiated by the data from the previous tests. For example, a special test was conducted with Norton's Wheelmate 811 because it was an emulsion containing both sulphur and chlorine. Another example was the selection of ADCOOL 2. This fluid was selected due to its low 50 gallon sump cost.

3.4 Grinding

This portion of the report will review the basics of grinding, describe the manufacturing procedures observed at RIA, review machining technologies rigorous testing procedures, and relate the results of these tests. This will be accomplished in the following seven subsections: Review of grinding, RIA grinding survey, Grinding cutting test fluid selection, Grinding test design, Machining Technology's test conditions, Grinding test results, and Conclusions.

3.4.1 Review of Grinding

The grinding operation may be compared to a milling operation with infinitely small teeth. Each small tooth is a grinding grain which can be compared to a turning tool with a negative rake angle. However, this is where the similarities end. The abrasive grains or grinding cutting elements travel at speeds 10-20 times of those used in milling operations. At this high speed the temperature at point of contact between the abrasive grain and the workpiece has been found to be at, or near the melting point of the workpiece, aided in part by the fact that grinding wheels are insulating ceramic materials. Tests run by M. C. Shaw (6) have indicated that instantaneous grinding

TABLE 3.3-3

RIA TEST FLUID MATRIX

Operation	Emulsion			Semi-Synthetic			Full Synthetic			Oil		
	LD	MD	HD	LD	MD	HD	LD	MD	HD	LD	MD	HD
Grinding	X			X	X		X	X				
Turning & Boring			X			X			X			
Milling			X			X			X			
Drilling & Taping		X				X			X			
Broaching												X

Key:

LD = Light Duty
MD = Medium Duty
HD = Heavy Duty

TABLE 3.3-4. RIA CUTTING FLUID ANALYSIS

COMPANY NAME	FLUID NAME	TYPE	S	C	P	CS	P	R	L	S	M	F	MIX	W	T.D/R	C50-T	G.D/R	C50-G	B.D/R	C50-B	C/GAL
ECONOMICS LAB	E P COOLANT	E	S	C			S	N	S	N	S	N	N	A	20	16.19	40	8.29	10	30.90	6.80
MASTER CHEMICAL	TRIM RD2-83A	E	S	C			B	N	N	N	N	N	P	A	0		0		7	66.97	
VALVOLINE	ADSOL 3	E	S	C			N	N	N	N	S	S	N	A	25	10.78	0		5	46.75	5.61
E.F.HOUGHTON	HOCUT 3210-X	E	S	C			N	G	S	N	N	S	N	A	25	13.46	40	8.53	10	31.81	7.00
NORTON	WHEELMATE 811	E	S	C			N	N	N	N	N	N	N	A	20	21.00	20	21.00	20	21.00	8.82
DOALL	POWER-CUT 390	E	S	C		F	N	G	S	S	S	S	N	A	20	21.42	40	10.97	5	75.00	9.00
GULF	GULF CUT HD	E	S				S	N	S	N	N	N	N	A	20	8.50	40	4.35	15	11.15	3.57
INTERNATIONAL R	IRMCO 335	E	S			LA	N	G	G	N	N	N	N	A	40	10.36	40	10.36	8	47.22	8.50
STUART OIL	DASCO 1149	E	S			F	N	S	S	N	N	S	N	A	25	11.25	30	9.43	15	18.28	5.85
STUART OIL	DASCO 1086	E		C			N	S	S	N	N	N	Y	A	25	7.26	30	6.09	10	17.18	3.78
SUN OIL	EMULSUN 51	E		C			S	N	S	S	S	N	N	A	20	7.76	40	3.97	10	14.81	3.26
STUART OIL	CODOL 0748	E		C		F	N	G	S	N	N	S	N	A	25	10.09	30	8.46	10	23.86	5.25
VALVOLINE	ADSOL 2	E		C			N	?	?	N	S	S	N	A	20	10.73	40	5.50	0		4.51
CIN. MILACRON	CIMPERIAL 1011	E		C		.S	N	N	N	N	S	N	N	A	20	16.66	20	16.66	20	16.66	7.00
MASTER CHEMICAL	TRIM SOL	E		C			S	N	B	N	S	N	DI	A	19	17.25	19	17.25	9	34.50	6.90
VAN STRAATEN	768	E		C		F	N	G	N	N	N	S	N	A	10	26.86	20	14.07	10	26.86	5.91
MOBIL OIL	MOBILMET 140	E				?	N	S	S	N	N	N	N	A	20	7.59	20	7.59	0		3.19
VALVOLINE	ADSOL 1	E					N	?	?	N	S	S	N	A	20	8.71	35	5.08	0		3.66
STUART OIL	SOLVOL 6633	E				F	N	G	S	N	N	N	N	A	25	9.46	30	7.93	15	15.37	4.92
OHIO IND. RES.	MASTERCUT	E				.S	N	N	N	N	S	N	N	A	20	10.66	40	5.46	10	20.36	4.48
MOBIL OIL	MOBILMET S-125	E				?	N	S	S	N	N	N	N	A	15	11.53	15	11.53	15	11.53	3.69
INTERNATIONAL R	IRMCO 303	E				FA	N	G	G	N	S	N	N	A	25	12.21	40	7.74	10	28.86	6.35
ECONOMICS LAB	MAGNACOOL 60	E				FT	N	N	S	N	S	N	PRE	A	0		40	7.18	0		5.89
GULF	GULFCUT SOL AL	E AL	S				S	N	S	N	S	N	N	A	20	5.71	50	2.35	10	10.90	2.40
DOALL	470 SOLUBLE OIL	E AL					N	S	S	N	S	S	N	A	10	18.40	30	6.53	0		4.05
VALVOLINE	ADCOOL 3	FS	S	C		PG	S	?	?	N	S	S	N	A	20	17.69	50	7.28	5	61.91	7.43
VALVOLINE	ADCOOL 1	FS					B	?	?	N	S	S	N	A	20	8.69	40	4.45	0		3.65
POLY-FORM OILS	POLY-AQUA	FS					S	N	N	N	N	N	N	A	25	9.51	30	7.98	10	22.50	4.95
INTERNATIONAL R	IRMCO 103	FS				FS	N	G	S	N	N	N	N	A	25	10.09	30	8.46	10	23.86	5.25
WYNN OIL	941 SYN	FS					S	N	N	N	S	N	N	A	20	10.47	30	7.09	7	27.50	4.40
VALVOLINE	ADCOOL 2	FS				PG	B	?	?	N	S	S	N	A	20	10.54	40	5.40	5	36.91	4.43
FREMONT	7011 AND AL	FS			P		S	G	N	N	N	S	N	A	30	10.67	60	5.42	20	15.76	6.62
FREMONT	7012 AND AL	FS			P		N	G	N	N	N	S	N	A	30	10.88	60	5.53	20	16.07	6.75
FREMONT	7013	FS			P		S	G	N	N	N	N	N	A	30	11.62	40	8.79	0		7.21
WYNN OIL	951-1 SYN	FS					S	S	N	N	S	N	N	A	25	12.38	50	6.31	10	29.27	6.44
E.F.HOUGHTON	HYDRA-CUT 496	FS			P		B	G	S	N	N	N	N	A	25	12.40	30	10.40	0		6.45
CIN. MILACRON	CIMFREE 238	FS				FA	S	N	N	N	N	N	N	A	25	12.50	30	10.48	20	15.47	6.50
STUART OIL	DASCOOL 427	FS					S	B	S	N	N	N	N	A	30	12.50	35	10.76	15	24.21	7.75
STUART OIL	DASCOOL 4408B	FS					S	G	S	N	N	N	N		20	13.04	0		10	24.90	5.48
NORTON	WHEELMATE 689	FS				P	N	N	N	N	N	N	N	A	20	17.23	20	17.23	0		7.24
ECONOMICS LAB	SYN LUBE HD	FS				?	N	N	S	N	N	N	N	A	30	17.72	40	13.40	0		10.99
TAPMATIC	ME II SUPER	FS					S	S	N	N	N	S	P	B	40	20.12	80	10.18	10	75.00	16.50
VAN STRAATEN	951	FS					S	N	S	N	S	N	N	A	10	21.18	20	11.09	10	21.18	4.66
DOALL	POWER-CUT HD600	FS			P		B	G	B	N	S	B	N	A	15	24.37	0		0		7.80
ECONOMICS LAB	MX5080	FS				?	N	N	N	N	N	N	N	Z	30	26.27	40	19.86	10	74.04	16.29
MASTER CHEMICAL	9106 CS	FS					B	N	B	N	N	N	N	A	0	330.00	24	13.20	0		6.60
ECONOMICS LAB	CC-6	O	Y				S	N	N	N	S	N			0		0		0	260.00	5.20
ECONOMICS LAB	C B 66	O	Y			FA	?	N	N	N	S	N		R	0		0		0	517.50	10.35
GULF	GULFCUT 21D	O	S	C			N	N	N	N	N	N		R	0		0		0	118.00	2.36
MOBIL OIL	MOBILMET GAMMA	O	S	C		FA	N	S	S	S	N	N		R	0		0		0	119.50	2.39
VAN STRAATEN	5299	O	S	C		FA	N	G	N	S	N	S		R	0		0		0	161.50	3.23
SUN OIL	SUNICUT 352	O	S	C		FA	N	N	N	S	S	S		R	0		0		0	163.00	3.26
DOALL	240 CUTTING OIL	O	S	C		FA	N	N	N	B	S	N		R	0		0		0	224.50	4.49
VALVOLINE	PROMAX 1022	O	S			FA	N	S	S	N	S	S		R	0		0		0	.00	.00
MOBIL OIL	MOBILMET SIGMA	O	S			FA	N	S	S	S	N	N		R	0		0		0	116.00	2.32
POLY-FORM OILS	TOPAZ-7/100	O	S		P	BF	N	N	N	N	N	N		R	0		0		0	180.50	3.61
GULF	GULFCUT 11D/AL	O				FA	S	N	S	N	N	N		R	0		0		0	104.00	2.08
ECONOMICS LAB	DO-5A	O				FT	S	N	N	N	S	N		R	0		0		0	264.00	5.28
NORTON	WHEELMATE 674	SS	S				N	N	N	N	N	N	N	A	20	16.50	0		20	16.50	6.93
VAN STRAATEN	550 P	SS		C			?	S	S	N	N	S	N	A	25	9.32	35	6.73	0		4.85
E.F.HOUGHTON	HOCUT 711	SS					S	G	S	N	S	S	N	A	25	8.21	30	6.88	0		4.27
STUART	DASCOOL 4379	SS					N	G	S	N	N	S	N	A	25	8.46	0		10	20.00	4.40
FREMONT	7030	SS			P		S	B	N	N	N	N	P	A	40	8.73	50	7.01	20	17.04	7.16
CIN. MILACRON	5 STAR 40	SS					S	N	N	N	N	N	N	A	25	11.00	30	9.22	20	13.61	5.72
STUART OIL	DASCOOL 502	SS				F	N	S	S	N	N	S	N	A	25	14.42	30	12.09	10	34.09	7.50

Key for Table 3.3-4

Table Headings

Type = Fluid Type
S = Sulfur
C = Chlorine
P = Phosphorus
CS = Others
P = Effect of fluid on machine paint and workpiece
R = Effect of fluid on rusting machine and workpiece
L = Effect of fluid on machine lubrication
S = Effect of fluid on staining machine and workpiece
M = Fluid mixing requirements
F = Does the fluid foam
W = Waste treatment
T.D/R = Turning dilution ratio
C50-T = Turning 50 gallon sump cost
C.G/R = Grinding dilution ratio
C50-G = Grinding 50 gallon sump cost
B.D/R = Broaching dilution ratio
C50-B = Broaching 50 gallon sump cost
C/Gal = Fluid cost per gallon

Chart Abbreviations

Type: E = emulsion, FS = full synthetic,
O = neat oil, SS = semi-synthetic
S: S = contains sulfur
C: C = contains chlorine
P: P = contains phosphorus
CS: F = FA = Fatty acids, S = Small % sulfur,
FT =PG = P = BF - special additives
P: S = slight, M = medium, B = bad, N - no
R: S = slight, M = medium, B = bad, N = no
S: S = slight, M = medium, B = bad, N = no
M: N = none, DI = use deionized water
W: A = acid split, R = recycle,
Z = can be put through city sewer

temperatures are in the order of 3000 degrees F. F. Sato (7) has shown that during surface grinding SAE 1035 or an equivalent steel, 84% of the heat developed was conducted into the uncut metal, 4% was transferred into the chip and 12% into the wheel.

During the grinding operation several processes can occur at the grinding wheel/workpiece interface. The grinding wheel's abrasive grains exhibit three distinct types of behavior or combinations of each depending upon their shape and radial distance from the wheel center (see Figure 3.4-1).

Rubbing - This is where the abrasive grain rubs on the work causing elastic deformation of the work material with negligible material removal.

Plowing - The plowing phenomenon occurs when an abrasive grain rubs deep enough into the workpiece to cause permanent plastic deformation. A groove is left on the surface, but no chip is formed and only a negligible amount of material is removed. Plowing results in excessive heat buildup, while strain energy from the deformation is transferred into the workpiece as well as the heat created by friction.

Cutting - An abrasive grain is cutting when a fracture occurs just ahead of the grain causing a chip to be formed. The cutting phenomenon predominates at the extreme outer radius the grinding wheel by sharp grains with negative rake angles. Dull grains require proportionally greater degrees of engagement with the workpiece before a chip can be produced.

The grinding wheel is being consumed by three wear processes. Attrition is the first form of wheel wear which is due to the high temperatures of the grinding operation. At these high temperatures, thermomechanical and chemical reactions between the abrasive and the workpiece or the surrounding atmosphere can occur very rapidly. This causes dulling of the abrasive grains which are referred to as wear flats. In these reactions the abrasive is eroded away. The number of wear flats per unit area of active wheel surface of grinding wheel is a possible measure of cutting fluid performance. The second form of grinding wheel wear is grain fracture. This occurs when the abrasive grain breaks to form a new sharp cutting edge. Bond fracture is the last form of wheel wear. This occurs when the grain is pulled from the grinding wheel. The amount of wheel consumed to remove a given volume of material, more commonly referred to as the G-ratio, is another method of cutting performance measurement. This will be explained in more detail in a later section.

Grinding wheels are considered to be hard when their binder is strong or contains more surface area on a grain (see Figure 3.4-2). Hard wheels hold their grits longer and thus are more susceptible to attritious wear. Hard wheels are used on softer material. Soft wheels break down faster to maintain grit sharpness and are usually used on hard materials. Lubrication properties in cutting fluids make grinding wheels perform as if they are softer.

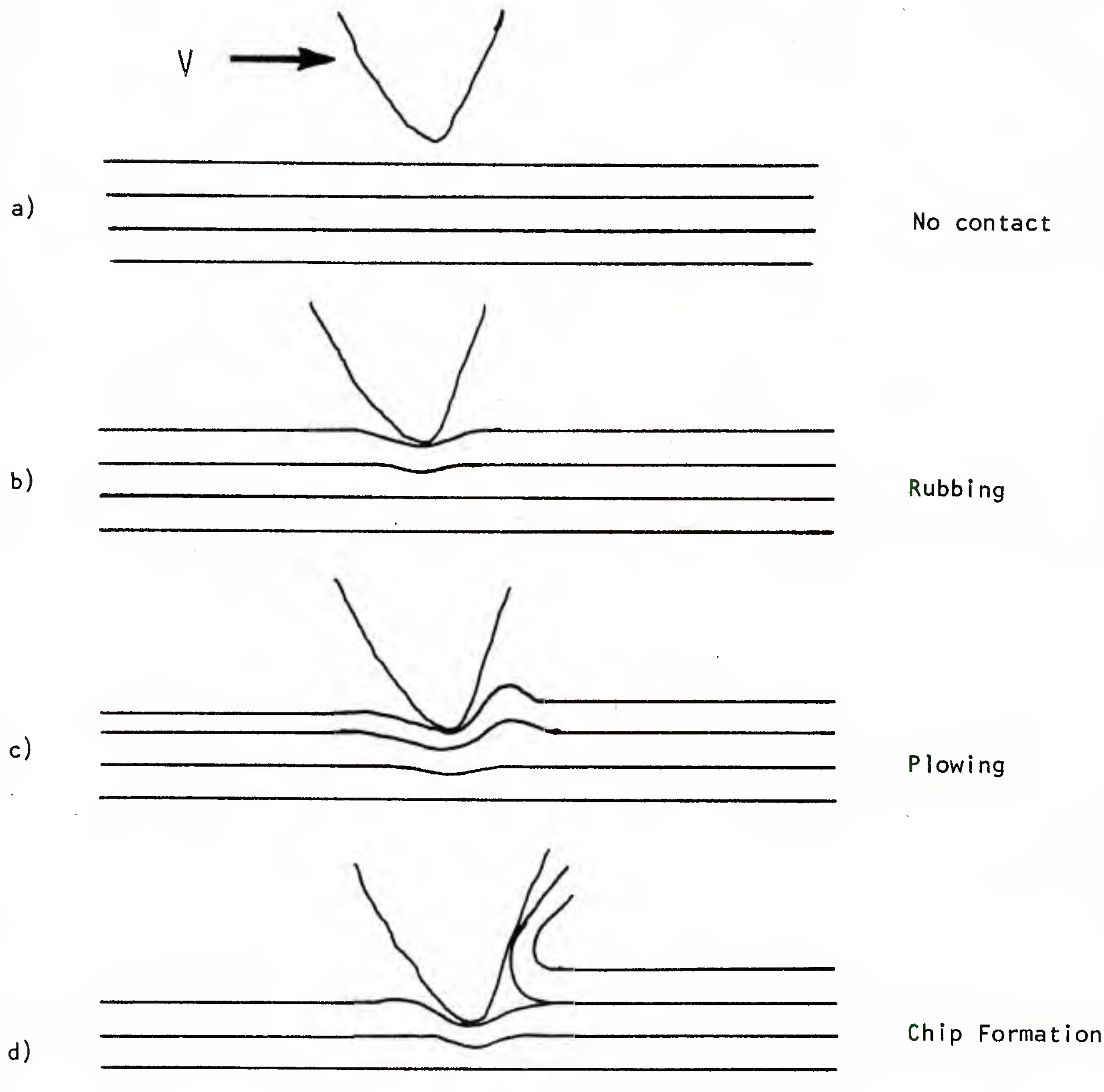


Figure 3.4-1. Various mechanisms which occur during grinding with increasing depths of cut per grain -- a) no contact, b) elastic deformation (rubbing), c) plastic deformation (plowing, burnishing) and d) chip formation.

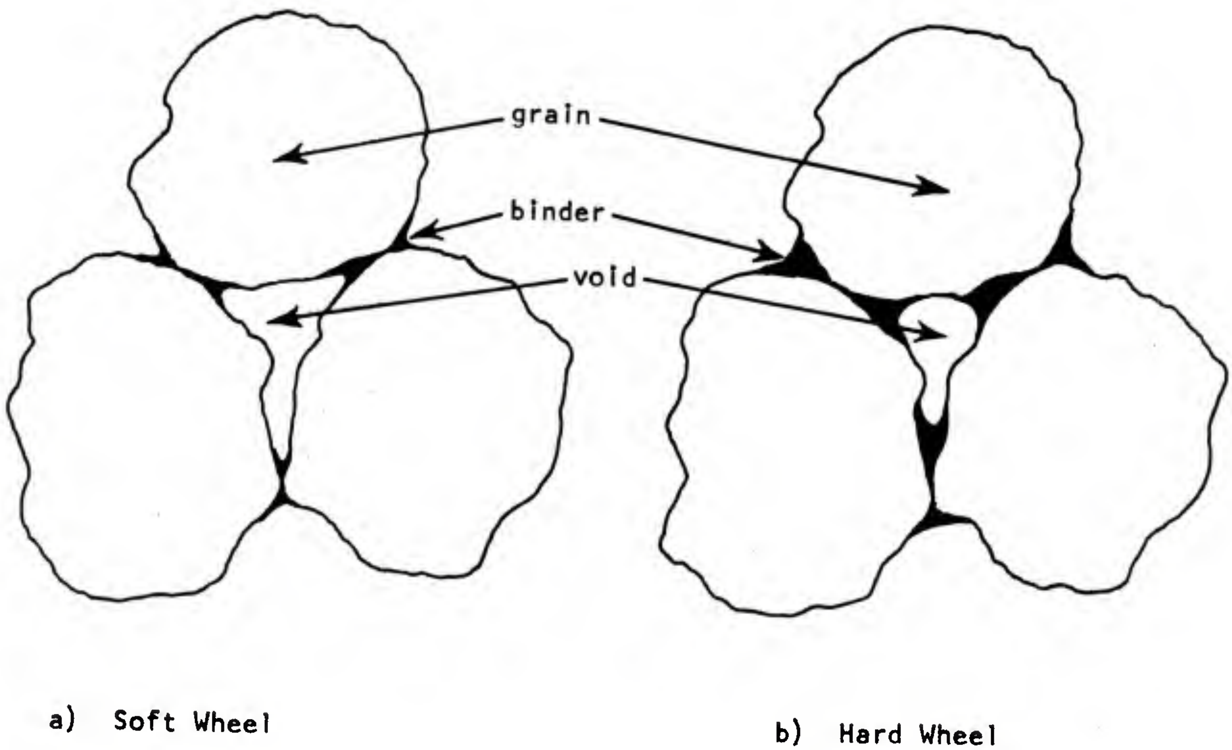


Figure 3.4-2. Representative cross-sections of a relatively hard and soft wheel demonstrating the different amounts of binder used and the bonding surface areas.

Grinding fluids should contain the following characteristics in order to achieve a satisfactory grinding condition:

1. Provide adequate cooling.

   The fluid should act as a heat conductor to carry away the heat from the grinding wheel and the workpiece.

2. Possess low surface tension.

   This will allow the fluid to penetrate the micro-openings and interstices at the wheel/workpiece interface.

3. Provide operator visibility.

   The fluid should be transparent to allow the operator to see reference points.

4. Prevent wheel clogging.

   A good cutting fluid will provide chemical action that will reduce wheel clogging from swarf.

5. Lubrication.

   Fluids that provide lubricity reduce friction at the wheel/workpiece interface and minimize the cutting temperatures.

6. Other factors.

   Properties such as rust prevention, bacteria control, mold control and operator acceptance are other factors that should be considered.

3.4.2 RIA Grinding Survey

A portion of the following represents a reiteration of Section 3.1. It is presented again here to add continuity to this discussion and allow section 3.4 to be complete in itself.

Grinding requirements for Rock Island Arsenal are somewhat different from most commonly encountered grinding operations. Grinding is typically used to machine hard or difficult to machine parts where other types of machining processes cannot be utilized. The unique feature at Rock Island is that the bulk of the material being ground is unhardened 4100 series steels. The surfaces being ground are most commonly mating surfaces which must be ground to specific tolerances to provide for adequate fitup during assembly, or to provide a sufficiently qualified surface for subsequent chrome plating. The chrome plating is used to provide superior wear resistance during service. Several production grinding operations were examined. These operations were done either on cylindrical or surface grinders and are presented in Table 3.4-1.

TABLE 3.4-1

RIA Manufacturing Process Data Analysis Sheet for Grinding

Part No.	Operation	Material	SFM	Infeed	Work Speed	Crossfeed	Hardness
10901204	OD Cylindrical Grind	4140	4200 (new wheel)	0.001 0.0005	50	1 in/rev	BHN 212/248
6538758 or 6538757	Surface Grind	4140	6021 (new wheel)	0.001 0.0005	35 35	0.200/pass 0.200/pass	NHS NHS
12007805	Surface Grind	4140	6021 (new wheel)	0.0005 0.00025	60 60	0.130/pass 0.130/pass	R_c30/35 R_c30/35
12012329	Cylindrical Grinder	Al-Br	6283 (new wheel)	0.001 0.0002	25 25	1.6 in/rev	NHS

Note: All crossfeeds are continuous and not incremental or consistent.

Key: SFM = Wheel velocity, surface feet per minute.
Infeed = Amount the grinding wheel moves radially per pass, inches.
Work Speed = The rate the workpiece moves past the grinding wheel,ft/min.
Crossfeed = Amount the grinding wheel moves axially per pass, inches.
NHS - No hardness specified.

Observations regarding grinding at Rock Island Arsenal may be summarized by the following:

1. Spindle speeds are governed by constant speed AC motors. Thus the actual surface speeds of the wheels decrease as the wheel radius decreases during use.

2. Infeeds are, in general, 0.001 inch for roughing operations and 0.0005 inch for finishing operations. These values can be attributed to limitations imposed by the flexibility of the parts being ground. Any larger infeed values would cause excessive part deflection creating tolerance problems.

3. On cylindrical parts, the crossfeeds are larger than those normally found in the Machinability Data Handbook. This would tend to load the part being ground in the axial direction, the direction in which the part is most rigid. The metal removal rates can then be increased without sacrificing tolerance.

4. For the surface grinding operations observed, the wheels were six inches in width. A large crossfeed could be used while producing a good finish with these wide wheels.

5. Specific levels of cross feed were found to be subject to considerable variation. Machine operators were free to select parameters on an individual basis to meet surface finish and size requirements.

6. Dressing was infrequently done as compared to most operations involving intricate forms or difficult-to-grind high temperature alloys. In most cases, dressing was done once every hour and was primarily required to remove wheel loading.

7. Relative to the previous observation, Cimfree 238 used at concentrations of approximately 100:1 is inadequate to prevent wheel loading, but prior attempts to use this product at richer concentrations has resulted in reports of operator problems. The lean concentration is also somewhat inadequate to prevent rusting of machines, fixtures, and occasionally workpieces.

3.4.3 Grinding Cutting Fluid Selection

The first stage of the grinding test was to evaluate all three basic generic types of cutting fluids: full synthetics, semi-synthetics, and emulsions. These fluids are numbered one through four in Table 3.4-2.

The first three of the fluids were prechosen because they were already being used at RIA or were proposed for use. Prior to testing these fluids were considered heavy or medium duty fluids. A low cost light to medium duty fluid was also selected as a comparison fluid (see fluid 4 in Table 3.4-2).

TABLE 3.4-2

Grinding Fluids Selected for Testing

Fluid #	Fluid	Manufacturer	Type	Strength	Chlorine	Sulfur	Other	50 Gallon Sump Cost
1	Trim Sol*	Master Chemical	E	HD	C			$17.25
2	Cimfree 238*	Cincinnati Milicron	FS	MD			++	10.48
3	Cimcool Five Star 40**	Cincinnati Milicron	SS	MD				9.23
4	Adcool 2	Valvoline Oil Company	FS	Low MD			+	5.40

Key:
E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic
HD = Heavy Duty
MD = Medium Duty
LD = Light Duty
\+ = Other Chemical or Additive
C = Chlorine
S = Sulfur

* Currently used at R.I.A.
** Proposed to be used at R.I.A.

The fluids selected represent all three generic types and will indicate if one generic type of cutting fluid is a superior grinding fluid.

3.4.4 Grinding Test Design

The grinding test was designed to simulate the observed RIA manufacturing process. Test parameters used are as follows:

Wheel Grade:	32A60M5VBE
Wheel Speed:	500 sfm
Table Speed:	60 ft/min.
Crossfeed:	0.250 in.
Total Depth of Cut:	0.025 in.
Infeed:	0.0005 in.
Dress:	Single Point (0.001/pass)
Material:	4140 steel

During the grinding test, various areas of interest were monitored. The cutting force and the normal forces were measured. Monitoring these values provides insight into the energy levels at the wheel-work interface. The lower these values the more effective the cutting fluid. Spindle horsepower was also monitored. The efficiency of metal removal can be assessed from the observed values of spindle horsepower. The lower the power the more efficient the cutting fluid.

Another valuable method of measuring grinding performance is the G-ratio. The G-ratio is defined as the volume of metal removed divided by the volume of abrasive which is consumed in the process. High G-ratios tend to be more desirable because wheel consumption can be minimized. This method could not be used to evaluate the RIA grinding tests because their grinding process produces G-ratios higher than can be measured practically. The fourteen-inch wheel diameter changes less than 0.00005 inch after 0.025 inch depth of cut grinding on a 4 x 6 inch test block. This produces 0.6 cubic inch of metal removed. The wheel volume consumed is less than 0.002 cubic inch (1 inch wide wheel x ($(7.0005)^2 - 7^2$)). Thus, the G-ratios were higher than 272 which is (0.6/0.0022). This value can be considered half of the actual because, when surface grinding in two directions, the wheel edge wears from both sides. Thus, the overall G-ratio as for all tests was larger than 544. Also, the tests did not produce enough wheel wear to necessitate wheel dressing.

Observing the grinding wheel before and after a test under a scanning electron microscope is yet another method to measure cutting fluid performance. The wear patterns of the wheel may be used to compare the effects of different cutting fluids and was the preferred technique for this program.

3.4.5 Test Conditions

All experiments were performed on an instrumented Brown & Sharpe 824 Micromaster surface grinder. Measurements of wheel speed were based on the observed spindle RPM's measured with a DC Tachometer and the existing wheel diameter. The table velocity measurement was taken directly from an LVT (linear velocity transducer). The instantaneous horsepower consumption was measured with a Hall-effect wattmeter connected to the spindle motor windings. The cutting and normal force was measured on a Honeywell 1858 visicorder oscillograph connected to a Kristal Instrument piezoelectric machining dynamometer.

3.4.6 Grinding Test Results

The overall test results which include observed power, normal forces and tangential forces are displayed in Table 3.4-3, overall grinding fluid test results; Figure 3.4-3, a graph of normal force vs. grinding fluids tested; Figure 3.4-4, a graph of tangential force vs. grinding fluids tested; and Figure 3.4-5, a graph of spindle power vs. grinding fluids tested.

Also, SEM evaluations of the condition of the grinding wheel for all the cutting fluids tested were made. Each wheel sample taken was compared to the other samples run with the other test fluids. The wheel sample having the lowest wear received the lowest number. These observations are displayed in Table 3.4-3. During the Cimfree 238 test, it was noted that this fluid had a superior ability to clean its wheel compared to the other fluids.

The data displayed indicates slight differences between the fluids tested. Interpretation of these data will be made in the preceding subsection.

3.4.7 Grinding Conclusions

The graphs and Table 3.4-3 in the previous section indicate that there are only slight differences between the four cutting fluids tested. A more definitive ranking of performance is accomplished by comparing all four cutting fluids normal forces or cutting forces to fluid number four's normal force. This is pictured in Figure 3.4-6, graph of percent improved normal force compared to Adcool-2. Note that at the most there is a twenty percent difference between each fluid.

This data supports the initial findings of the RIA survey that are presented in Section 3.4-2 which indicated that the grinding operations at RIA are not severe. Utilizing these data, the following factors become dominate in choosing a cutting fluid for the Rock Island Arsenal.

1. Price to fill the sump compared to performance gained
2. Sump life of the fluid
3. Disposal cost
4. Transparency of the fluid
5. Ability of the fluid to clean the grinding wheel

All of these factors have been addressed thus far except disposal cost which will be explored in the final phase of the RIA cutting fluid program. A review of the 50 gal.

TABLE 3.4-3

Overall Grinding Fluid Test Results

Fluid No.	Fluid Name	Manufacturer	Fx (lbs.) Tangential Force	Fy (lbs.) Normal Force	Power (H.P.)	SEM
1	Cimfree 238	Cincinnati Milicron	10.12*	18.72*	1.535*	2
2	Trim Sol	Master Chemical	10.98	20.98	1.620	1
3	Cimcool Five Star 40	Cincinnati Milicron	12.62	21.70	1.903	4
4	Adcool 2	Valvoline Oil Company	12.76	22.54	1.903	3

* Averaged Data

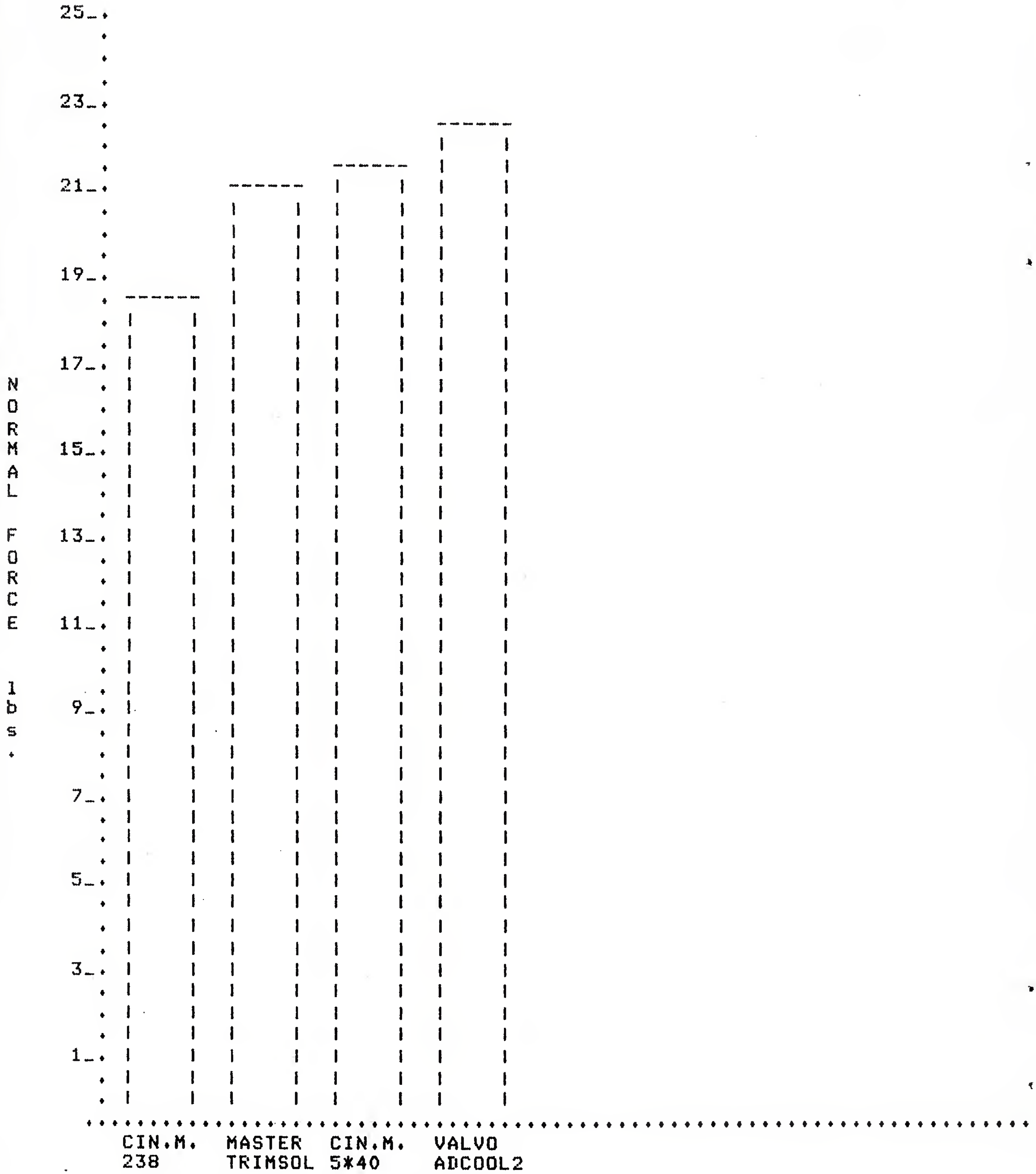


Figure 3.4-3. Normal Force vs Grinding Fluids Tested.

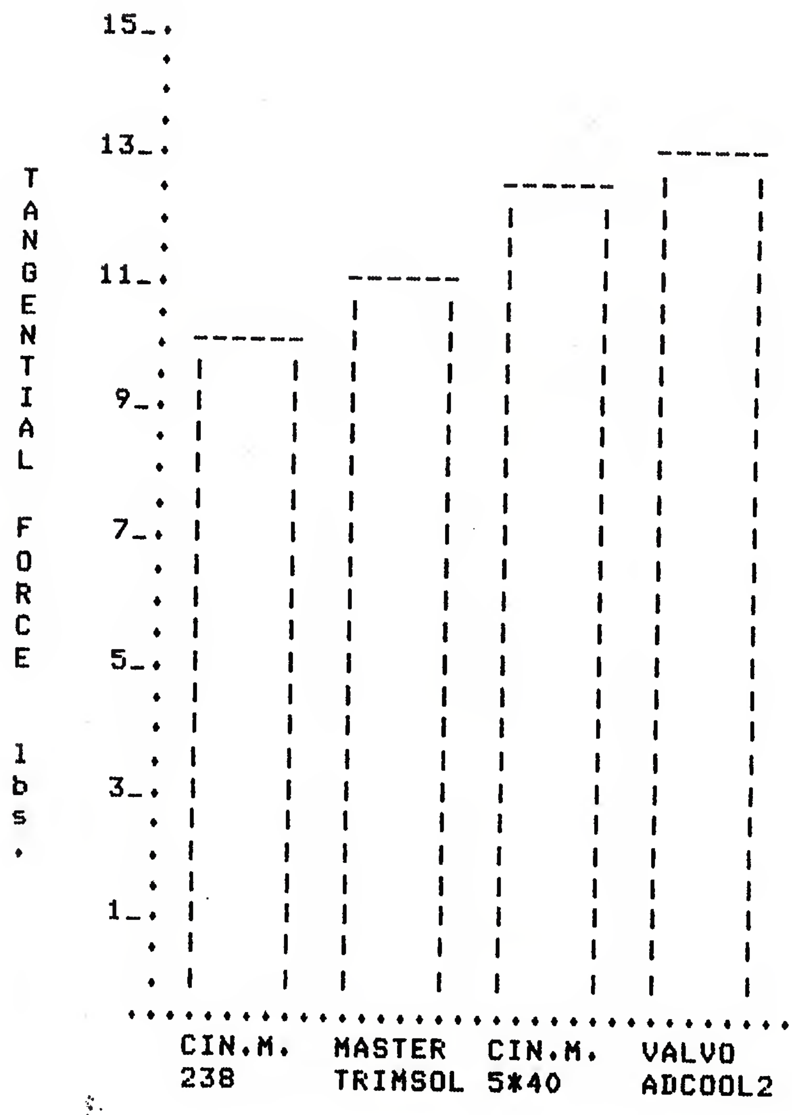


Figure 3.4-4. Tangential Force vs Grinding Fluids Tested.

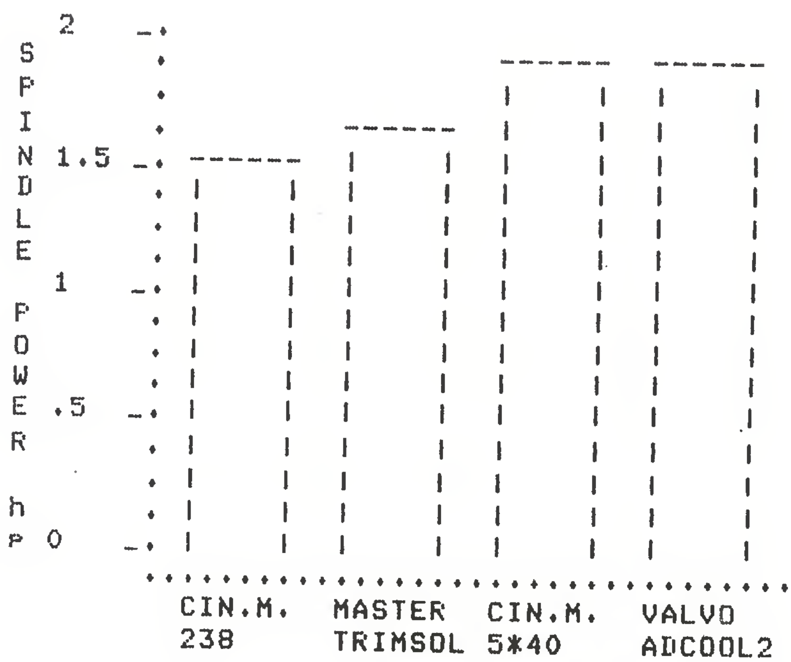


Figure 3.4-5. Spindle Power vs Grinding Fluids Tested.

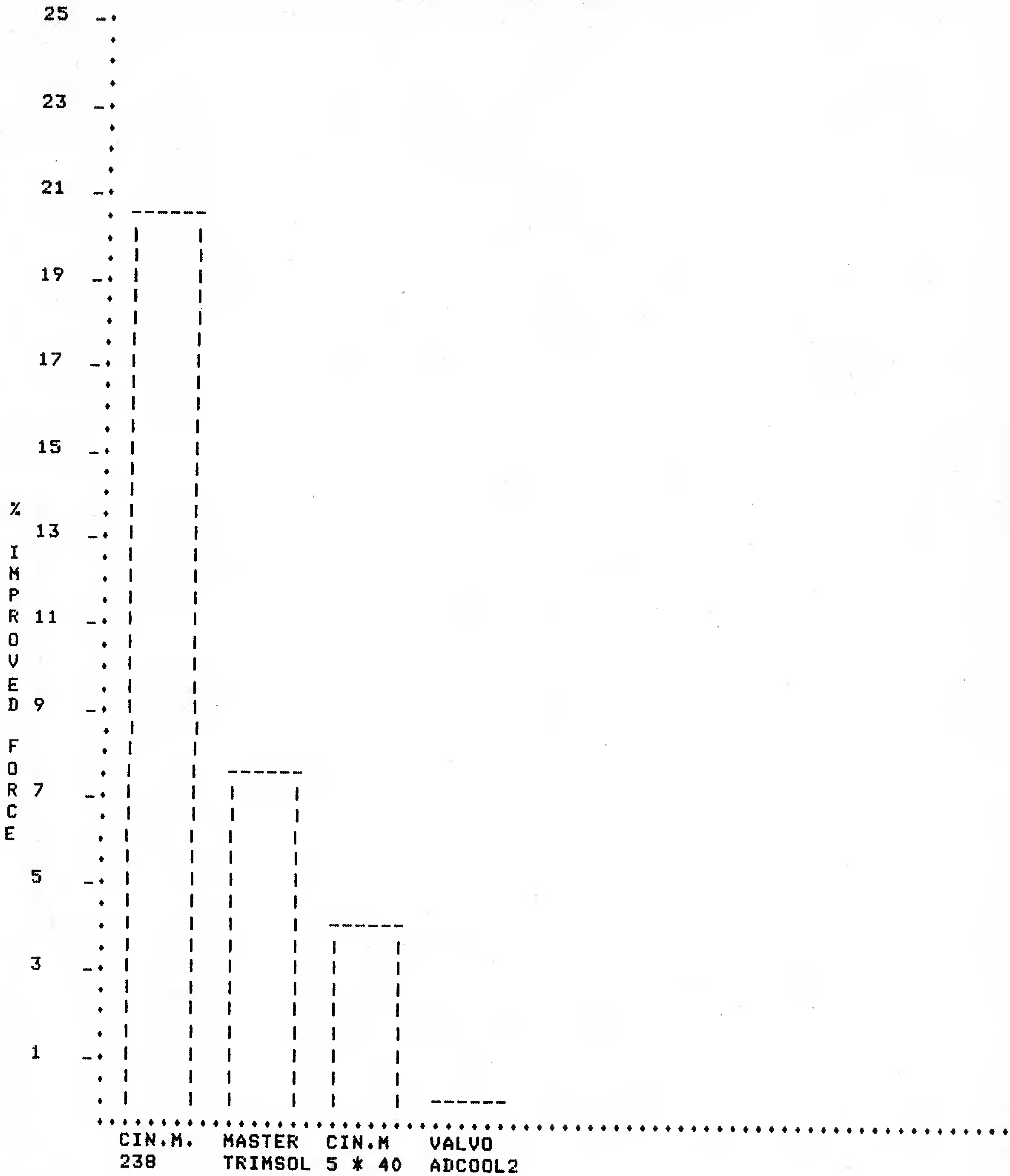


Figure 3.4-6. Percent Improved Normal Grinding Force Compared to ADCOOL-2.

sump costs indicates that Adcool-2 has the lowest cost (see Figure 3.4-6) of $5.40. Test results indicate that Cimfree 238 has the lowest force levels and also possesses a superior ability to clean the grinding wheel. The cost of Cimfree 238 is almost twice the amount of Adcool-2 at $10.48 to fill a 50 gallon sump (see Figure 3.4-7).

A more complete economic analysis would have to be made to determine if the twenty percent increase in performance will pay for the increased sump cost. However, generally speaking the reduction in dressing should pay for this additional cost.

Also, the grinding fluid flow has just as important an effect on grinding as the selection of the cutting fluid (see Table 3.4-4). Notice that in some cases there is as much as a 25% increase in forces and a 24% increase in power using a slightly lower fluid flow (see Figure 3.4-8). These force and power increases are a result of the reduction of cooling caused by the cutting fluid flow reduction. This phenomenon demonstrates that a grinding fluid's number one function at the RIA is cooling.

3.5 Turning and Boring

The turning and boring section will review the basics of turning, describing the manufacturing procedures observed at RIA, review Machining Technologies testing procedures and relate the results of these tests. These topics will be presented in the following subsections: Review of turning, RIA turning and boring survey; turning and boring cutting fluid test selection; turning and boring test design; Machining Technology's test conditions, turning test results and conclusions.

3.5.1 Review of the Basics of Turning

Turning is a basic machining operation that produces cylindrical parts on an external surface. This is accomplished with a rotating workpiece being machined with a single point cutting tool fed in the direction parallel to the axis of the workpiece. There are three main factors that describe a turning operation which are: speed, feed and depth of cut. Speed is the relationship between the workpiece surface and the cutting tool. This value is the product of the rotating speed times the circumference, in feet, of the workpiece before the cut. This calculation is expressed in surface feet per minute (SFM) and the standard calculation formula is displayed below.

$$SFM = (.262) \times (\text{diameter in inches}) \times (R.P.M.)$$

Feed refers to the cutting tool and is the rate at which the tool advances along the cutting path. Usually the feed rate is directly related to the spindle speed on a power-fed lathe and is expressed in inches of tool advances per revolution of the spindle (IPR). Also, the feed can be expressed as the inches per minute (IPM) the tool moves. Depth of cut (DOC) is the thickness of the layer of material that is being removed from the workpiece. The diameter of the workpiece is reduced by two times the depth of cut. Figure 3.5-1 illustrates these turning parameters. Boring is a similar operation used to generate internal cylindrical surfaces.

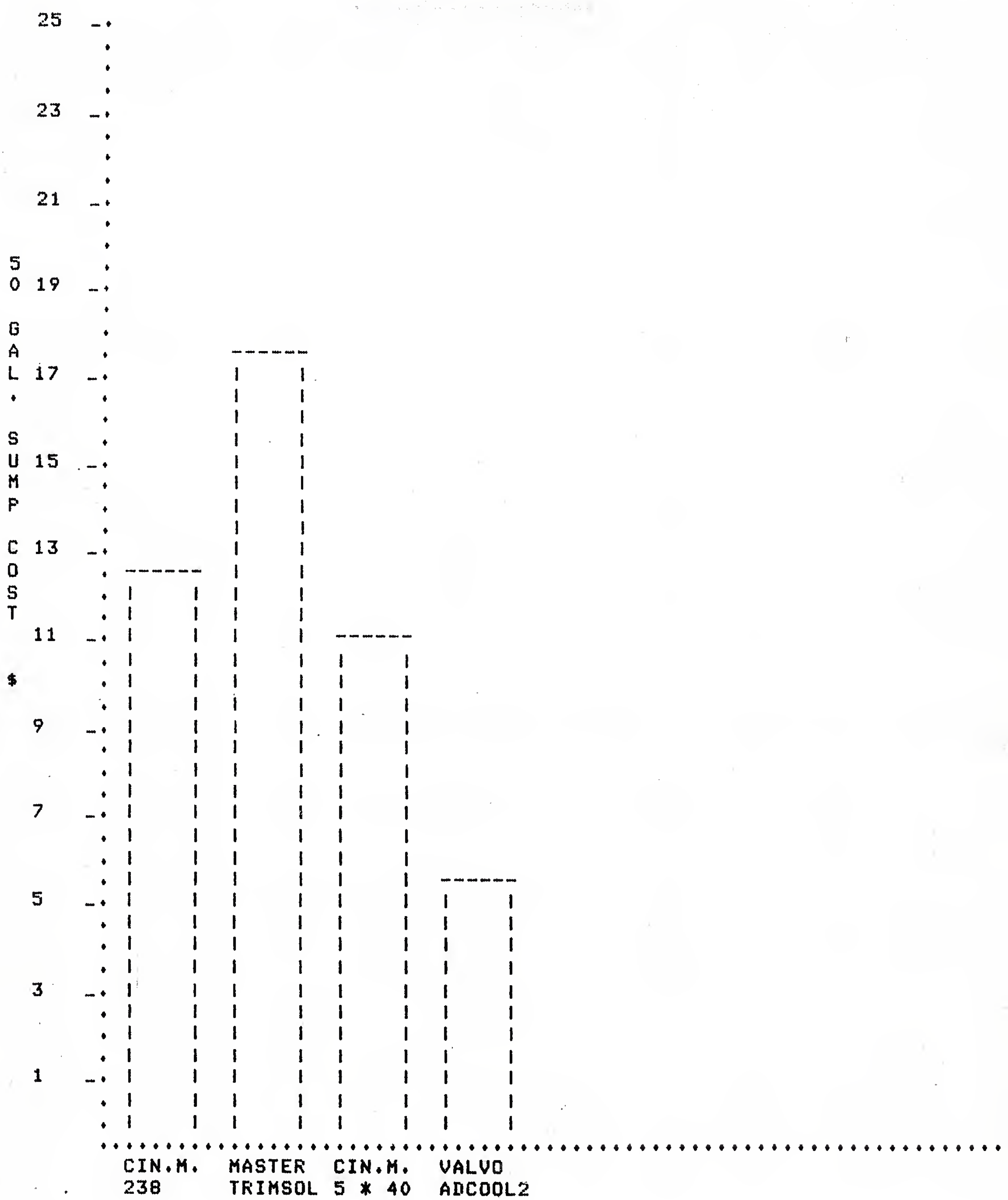


Figure 3.4-7. Price to Fill a 50 Gallon Sump vs Grinding Fluids Tested.

Table 3.4-4

GRINDING TEST RESULTS USING LOW FLUID FLOW

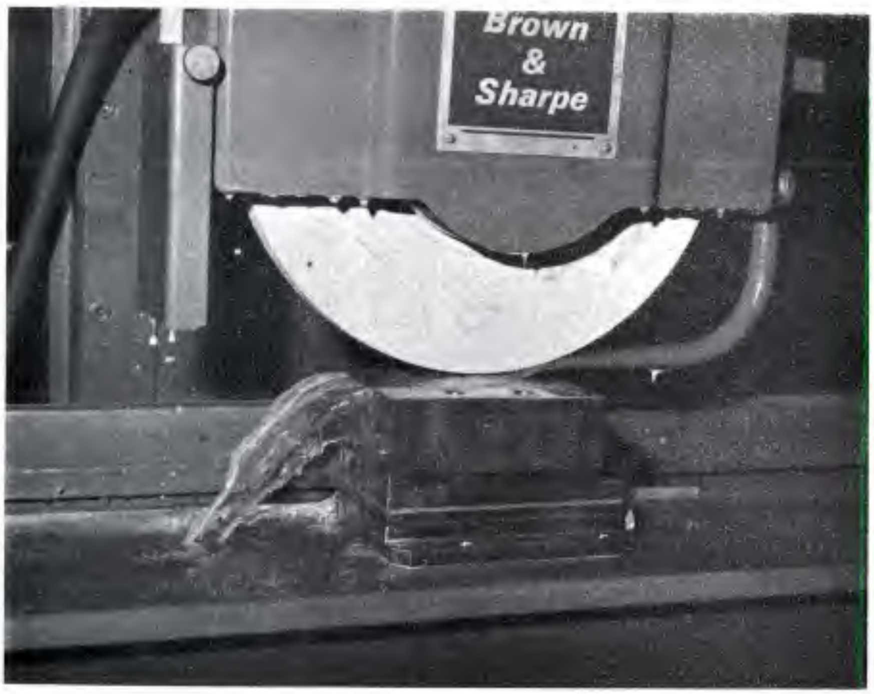
Fluid #	Fluid	Manufacturer	Fy (lbs)	% Increase	Fz Lbs.	% Increase	Power (H.P.)	% Increase
1	Cimfree 238*	Cincinnati Milacron	12.70	25.5	22.36	19.4	1.96	27.7
2	Trim Sol*	Master Chemical	13.47	22.7	23.38	11.4	2.09	29.0
3	Cimcool Five Star 40**	Cincinnati Milacron	13.87	9.9	23.28	7.2	1.98	4.0
4	Trim 9106CS	Master Chemical	13.83	22.69	22.69		2.12	

% increase - these numbers compare the low fluid flow tests to the normal fluid flow tests

* Used at R.I.A.

** Proposed to be used at R.I.A.

Normal Flow



Low Flow

Figure 3.4-8. A Photograph Showing a Normal and Low Cutting Fluid Flow Rate.

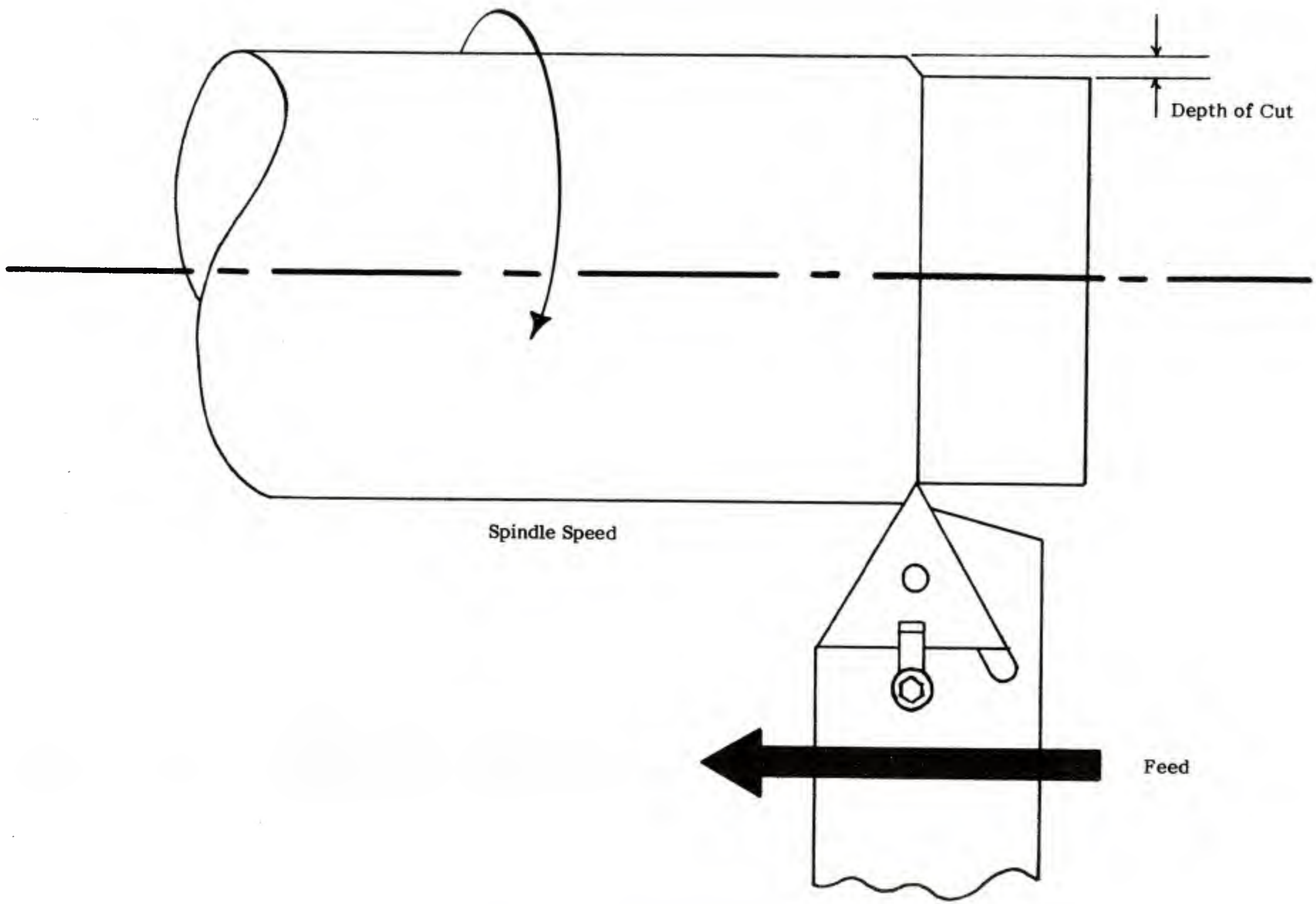


Figure 3.5-1. Turning Parameters.

Other factors, such as material type, material hardness, and tool selection also influence the turning operation. Material type and hardness have a major effect on the turning operation. In general, the harder the material the more difficult it is to machine. This usually causes an increase in cutting temperature which is a result of an increase in friction. Material type and hardness dictate the speeds, feeds and depth of cut at which the turning operation may be operated. A soft material, such as aluminum, may be run at higher SFM's, feed rates and DOC's than 4100 series steels.

The tooling used is another important governing factor in a turning operation. Currently, there are many tool compositions available for turning: high speed steel, various cemented carbides, and, more recently, ceramics. All of these types of tools have optimal feeds, speeds, depth of cuts and material types they work best with. However, to delve deeper into this subject would go beyond the scope of this report. Many tests and magazine articles have been written on this subject (8, 9, 10).

The turning and boring cutting fluid should have the following characteristics:

1. Provide adequate cooling.

   The fluid should act as a heat conductor to remove the heat from the tool/workpiece and tool/chip interfaces.

2. Possess a low surface tension.

   This will allow the fluid to penetrate into the micro-openings and cracks at the tool/workpiece and tool/chip interfaces.

3. Provide lubrication.

   Reduce the high frictional forces associated with turning which is accomplished by shortening the cutting shear plane.

4. Other factors.

   Properties such as rust prevention, bacteria control, mold control and operator acceptance are other factors that should be considered.

3.5.2 RIA Turning and Boring Survey

A portion of the following represents a reiteration of Section 3.1. It is presented here again to add continuity to this discussion and allow Section 3.4 to be complete in itself.

Seventy-five percent of the observations for turning and boring exhibited either extreme wear due to chipping or extreme wear due to cratering without evidence of flank wear or built-up edge (BUE) effects (see Table 3.1-3). This observation indicates that the desired balanced wear between cratering and flank wear is not being achieved. Examples of the observed extreme crater wear for turning and boring may be viewed in Figure 3.1-5. The scanning electron microscope (SEM) photomicrographs indicate that excessive crater wear and minimal flank wear are already evident.

On-site observations indicated that the present methods for physical fluid application appeared to be adequate. Sufficient cutting speeds for carbide tools, 300-600 SFM, for the most part were achieved which essentially eliminated the possibility for the built-up edge mode of wear. The exceptions were when older low-speed machines were utilized. In some cases tool rigidity or using too hard of a carbide grade may have also contribued to initiate chipping. Insufficient concentration of the present cutting fluid or the utilization of an inadequate cutting fluid has the highest probability of being the primary cause of premature tool failure by the undesirable chipping mode.

A summary of the turning and boring machining data collected at RIA is displayed in Table 3.2-1 and Table 3.2-2. This information was used to select the test parameters used.

3.5.3 Turning and Boring Cutting Fluid Test Selection

Initially, all three generic types of cutting fluids were to be tested and compared to a base cutting fluid without E.P. additives. The base fluid is number one in Table 3.5-1 and the initial test fluids are numbered two through four. All of the initial test fluids except number one are considered medium to heavy duty. Fluid number two was chosen as a test fluid because it is currently being used at RIA. Fluid number three was selected because it was used in the previous grinding tests and information was needed to determine if a good grinding fluid could also be a good turning fluid. The semi-synthetic fluid number four was selected because of its low sump price and it contained the same E.P. additive, chlorine, as test fluid number two, which is the current standard fluid at RIA. Fluid number five was tested because it contained only sulfur which is usually considered the most heavy duty E.P. additive considered. Sulfur usually becomes active at higher temperatures than chlorine. The combined effects of chlorine and sulfur would be observed during the testing of fluids number six and seven. Test fluid seven was also said by its manufacturer to possess the ability to reduce cobalt binder degradation. Test fluid eight was tested because it was the only fluid supplied that could be disposed of by pouring it directly into a city sewer system without waste treatment.

3.5.4 Turning and Boring Test Design

The boring test was combined with the turning test due to the similarities of both processes. All of the turning tests were conducted at the severest turning parameters used at RIA. These test parameters are as follows:

TABLE 3.5-1

TURNING AND BORING FLUIDS SELECTED FOR TESTING

Fluid Number	Fluid	Manufacturer	Strength	Type	C	S	Others	50 Gal Sump Cost
1	470	DoAll	LD	E				$18.40
2	Trimsol*	Master Chem.	HD	E	C			$17.25
3	Cimfree 238*	Cin. Milacron	MD	FS			++	$12.50
4	550-P	Van Straaten	MD	SS	C			$ 9.33
5	Wheelmate 674	Norton	HD	SS		S		$16.50
6	Wheelmate 811	Norton	HD	E	C	S		$21.00
7	Adcool-3	Valvoline	HD	FS	C	S	+	$17.69
8	MX 5080	Economics Lab.	HD	FS			+	$26.27

Key:

LD = Light Duty
MD = Medium Duty
HD = Heavy Duty

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

C = Chlorine
S = Sulfur
+ = Other

Tooling:	Carboloy TNMA-543E-370, uncoated carbide inserts
SFM:	800 surface feet per minute
Feed Rate:	.0153 inches per revolution
Depth of Cut:	.050 inches
Material:	4140 steel
Fluid Application:	Single pipe at a flow rate of 2 gallons per minute
Test Run Length Criteria:	Each test was continued until the minimum of .030 flank wear was observed

3.5.5 Test Conditions

All tests were performed on a Model 60 Monarch lathe located in the machining research laboratory of the Colwell Engineering Center. The testing arrangement is shown in Figure 3.5-2, which illustrates the relationships of the cutting tool to the workpiece and the cutting fluid application system. The tool holder was mounted on a Kristal Instrument, Piezoelectric Machining Dynamometer, which permitted evaluation of the three orthogonal forces generated while cutting (see Figure 3.5-3). The power was monitored by a Valenite power monitor connected directly to the spindle motor of the lathe. The output signals from the power monitor and the dynamometer were recorded in analog form on a Honeywell 1858 Visicorder Oscillograph. The signal data were later reduced to digital values employing sensor calibration factors and measuring the signal trace deflection at the point of interest within the machining event. Tool wear measurements were ascertained off-line utilizing a Gaertner toolmaker's microscope. In keeping with the majority of metal cutting research work, tool wear was defined as the maximum length of the wear pattern observed on the tool flank face.

3.5.6 Turning Test Results

Flank wear was measured for each cutting fluid evaluation after turning successive increments of six inches in the X-direction. This procedure was continued until at least .030 of an inch of flank wear was measured. These data were taken and a linear regression analysis was performed on them. A sample linear regression for fluid number two is displayed in Figure 3.5-4. The majority of the linear regressions were calculated utilizing six data points. Some tests used five points due to increased tool wear.

Understanding what the linear regression equation represents and how it is formulated is important when interpreting the test results. Figure 3.5-4 shows the basic two-part form of the linear regression: the slope (.000533) and the intercept (.01466).

The steady state condition which occurs after the tool's initial "break in" and before catastrophic failure is described by the slope. This steady state condition takes on a linear relationship that describes the development of the tool's wear scar. The slope may be used to compare the relative performances of cutting fluids. Good cutting fluids will have a lower slope while poorer cutting fluids will have steeper slopes.

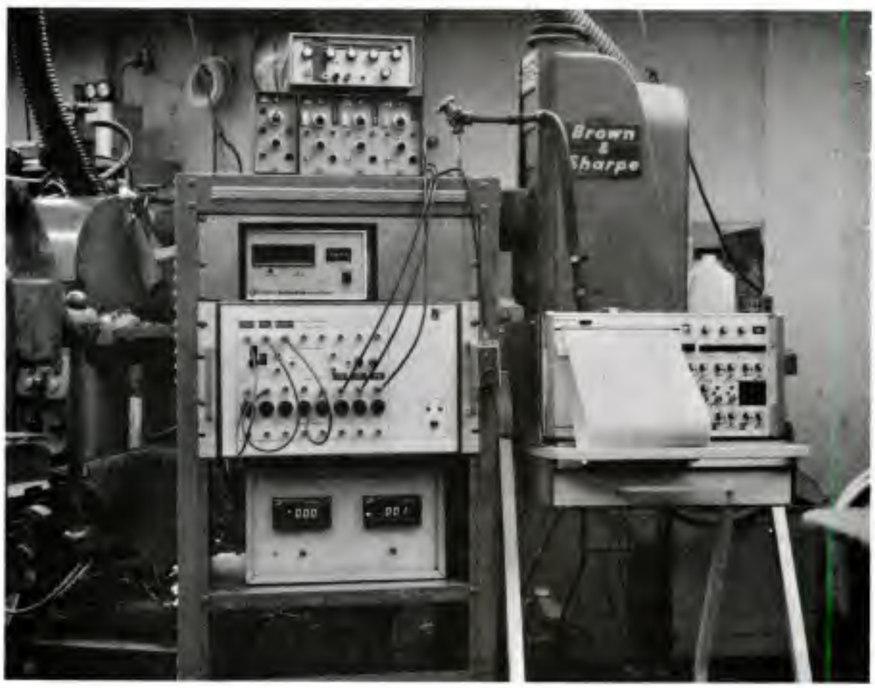


Figure 3.5-2. Turning Test Arrangement.

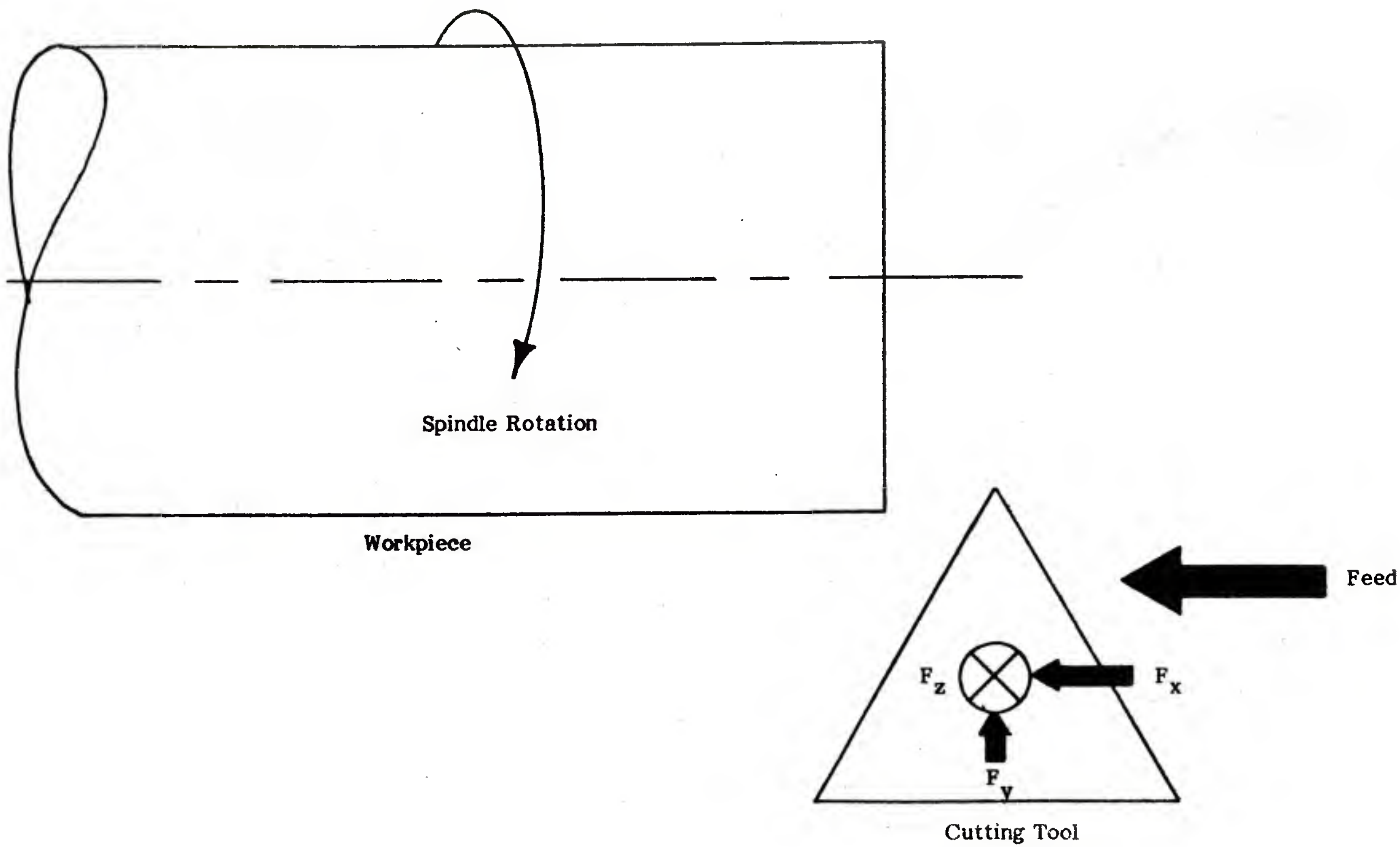


Figure 3.5-3. Dynamometer Force Configuration.

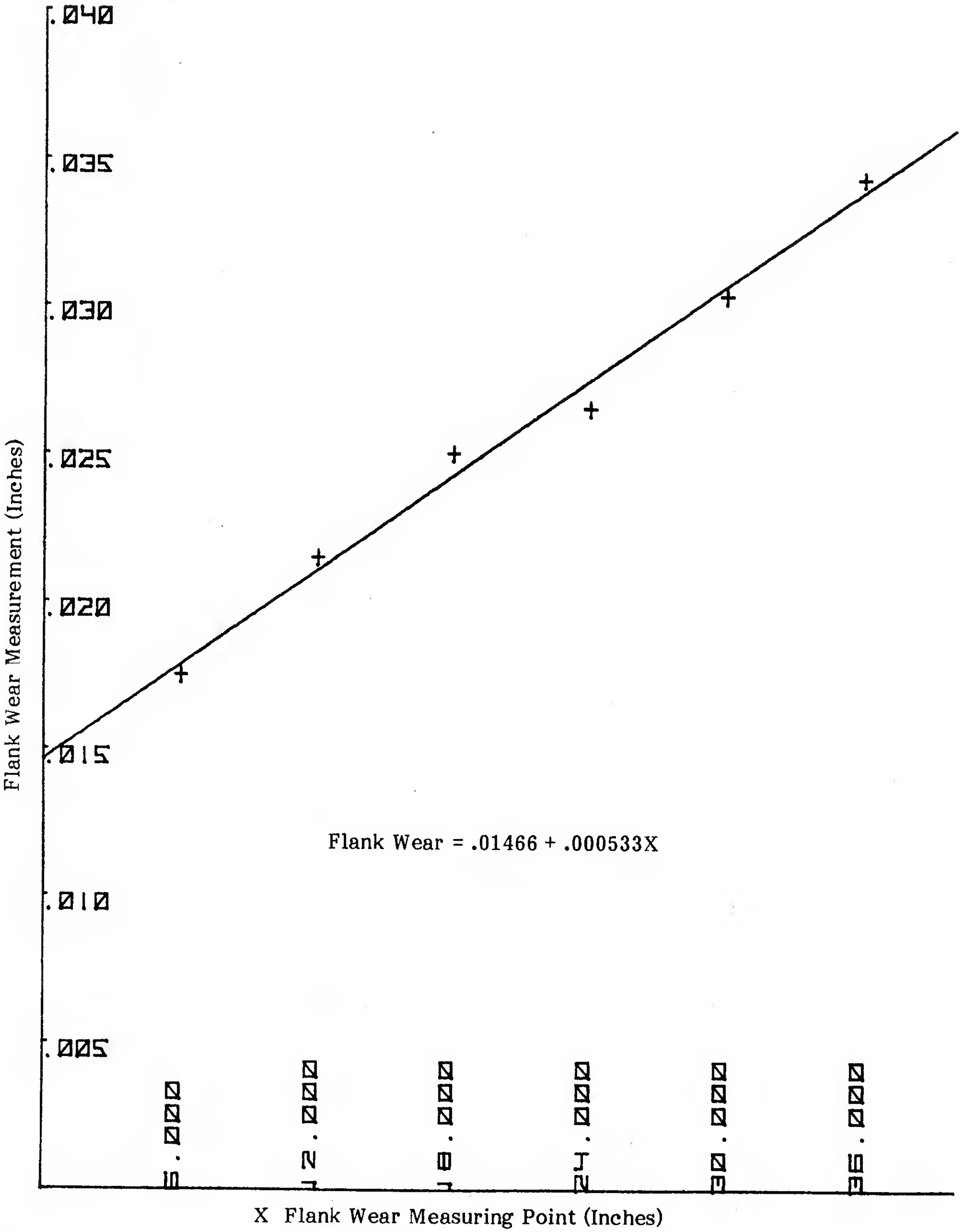


Figure 3.5-4. Sample Linear Regression for Fluid Number Two.

The intercept value is not a direct physical measurement but it in effect represents the cumulative results of rapid tool wear which occurs on a new tool edge during the initial stages of a cut. This value is obtained by merely extrapolating the steady-state wear rate back to its intersection of the flank wear axis at zero cutting time. Variations observed in the values of this intercept are primarily a function of variations in individual cutting edges. There may be minor contributions to this break-in process attributable to the cutting fluid, but the major effects are primarily related to the cutting tool.

The amount of metal removed to reach .030 of an inch of flank wear was calculated for each test fluid using the linear regression analysis data. An average value was used for the intercept when calculating these values because its value is directly influenced by the initial cutting edge of individual tools which are subject to some variation. This will allow all of the test fluids to be compared from the same initial starting point.

Force and power data was also collected during each six-inch X-direction turning cut. Five or six data points were averaged for each test fluid depending on when the tool reached .030 of an inch of flank wear. The power and force values were measured at the end of each six-inch X-direction turning cut.

The results of these analyses are displayed in Table 3.5-2. Also, no excessive flank wear, cratering or chipping was observed during the tests or the SEM evaluations.

3.5.7 Turning and Boring Conclusion

Two histogram graphs were computed from the data displayed in Table 3.5-2. The first graph is displayed in Figure 3.5-5 and shows the cubic inches of material removed before the cutting tool used with that fluid reached .030 of an inch of flank wear. Also, each cutting fluid was compared by percentage of increased tool life to test fluid number four. This graph is displayed in Figure 3.5-6. The graphs indicate three levels of fluid performance; the first group having a low performance increase of 34% and the second group having a moderate increase of 50% to 66%. As much as a 100% improvement in tool life is experienced in the third group. These latter data are displayed in more detail in Table 3.5-3. Also, a histogram relating the different prices are presented in Figure 3.5-7.

These results seem to indicate that high performance, medium performance and low performance groups of cutting fluids exist for the test parameters utilized. Note that the lower sump cost fluids have a higher peformance capability. Cincinnati Milacron's Cimfree 238 has the lowest sump cost with the highest performance level in group two. Trimsol has the highest performance level of all the cutting fluids tested and is the only fluid in group three.

TABLE 3.5-2

TURNING TEST RESULTS

Fluid Number	Fluid	Manufacturer	Linear Regression Slope	Linear Regression Intercept	IN^3 Removed	Avg. Fx(Lbs.)	Avg. Fy(Lbs.)	Avg. Fz(Lbs.)	Avg. Power(H.P.)
1	470	DoAll	.000891	.016977	13.70*	144.80	158.20	301.20	8.00
2	Trimsol	Master Chem.	.000533	.014660	20.41	141.83	157.83	298.00	8.33
3	Cimfree 238	Cin. Milacron	.000654	.016027	16.95*	139.00	158.33	296.00	8.13
4	550-P	Van Straaten	.001317	.011533	10.20	142.00	165.33	303.33	8.77
5	Wheelmate 674	Norton	.000823	.013420	16.30	147.50	161.17	305.67	8.54
6**	Wheelmate 811	Norton	.000811	.015626	16.59	143.00	162.60	304.00	8.21
7	Adcool-3	Valvoline	.000708	.014280	15.34	143.50	161.00	300.33	8.69
8	MX-5080	Economics Labs	.000797	.015500	13.66	138.40	157.00	297.00	8.43

* Averaged data

** Tested at less than 800 SFM

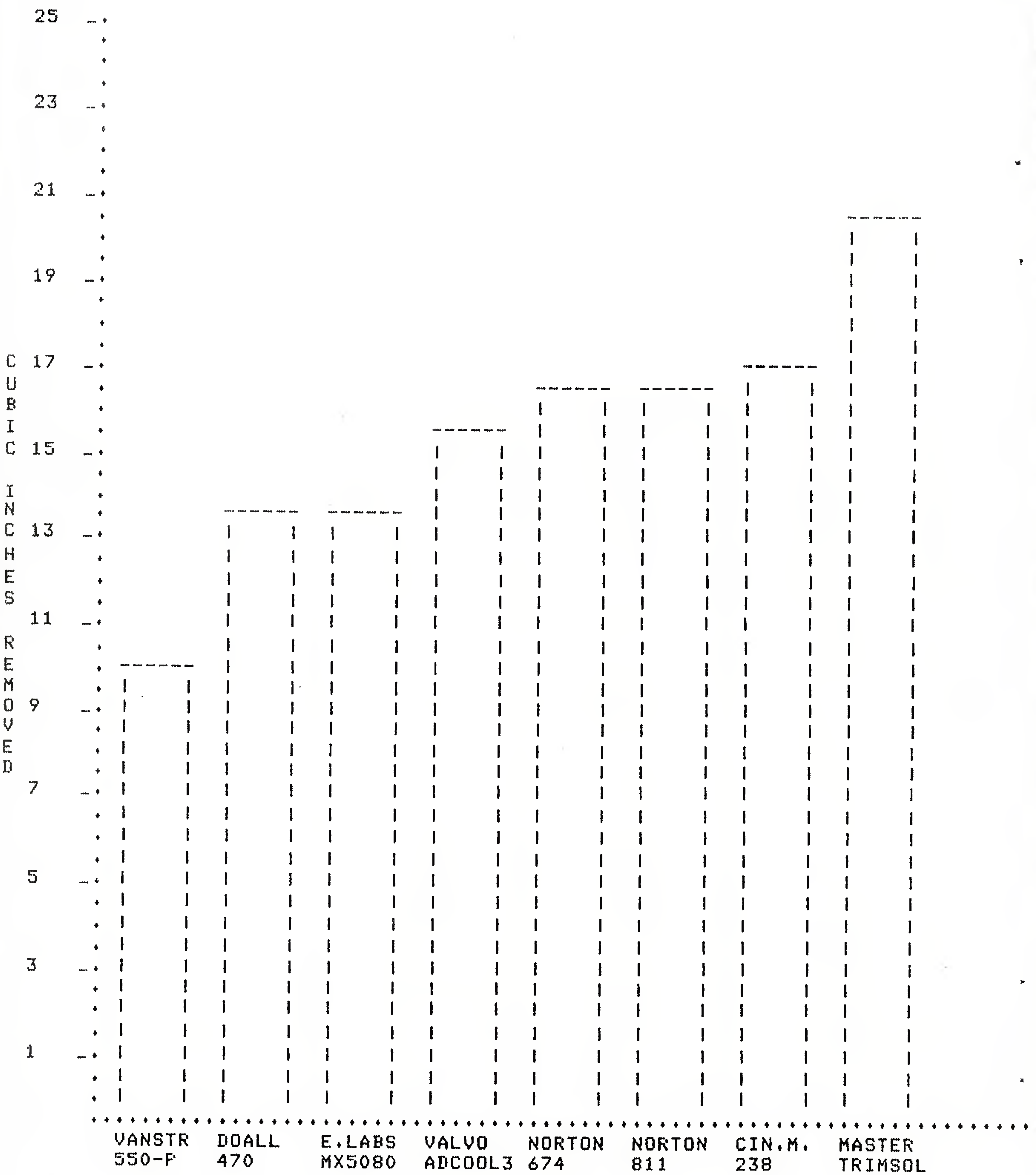


Figure 3.5-5. Cubic Inches of Metal Removed to .030 of an Inch of Flank Wear vs Turning Fluids Tested.

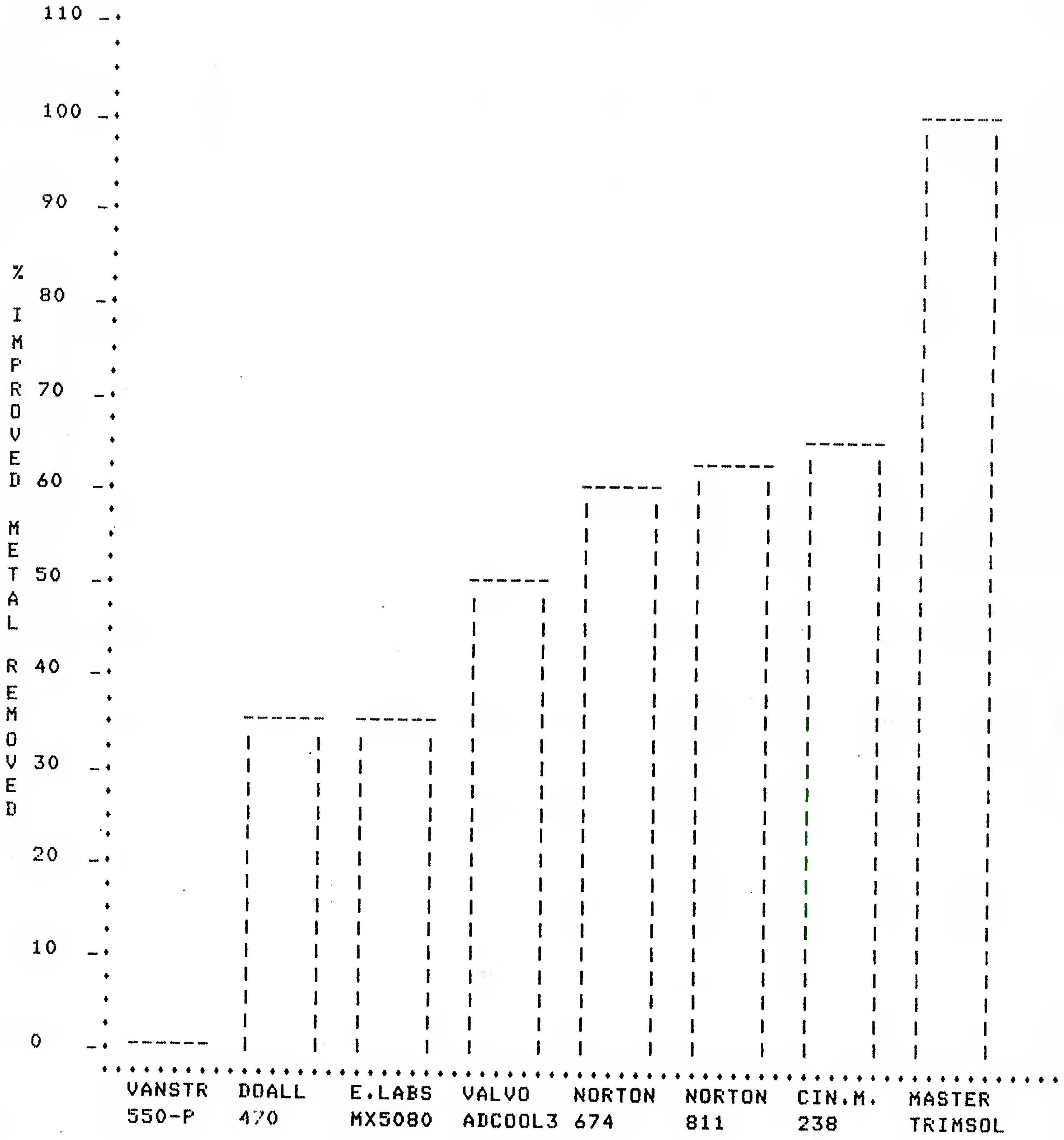


Figure 3.5-6. Percent of Increased Tool Life Compared to Van Straaten 550-P.

TABLE 3.5-3

CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	550-P	Van Straaten	SS	C			$ 9.33
	470	DoAll	E				$18.40
	MX-5080	Economics Labs	FS			+	$26.27
2	Adcool-3	Valvoline	FS	C	S	+	$17.69
	Wheelmate 811	Norton	E	C	S		$21.00
	Wheelmate 674	Norton	SS		S		$16.50
	Cimfree 238	Cin. Milacron	FS			++	$12.50
3	Trimsol	Master Chemical	E	C			$17.25

Key:

1 = Low Performance
2 = Medium Performance
3 = High Performance

C = Chlorine
S = Sulfur
+ = Other

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

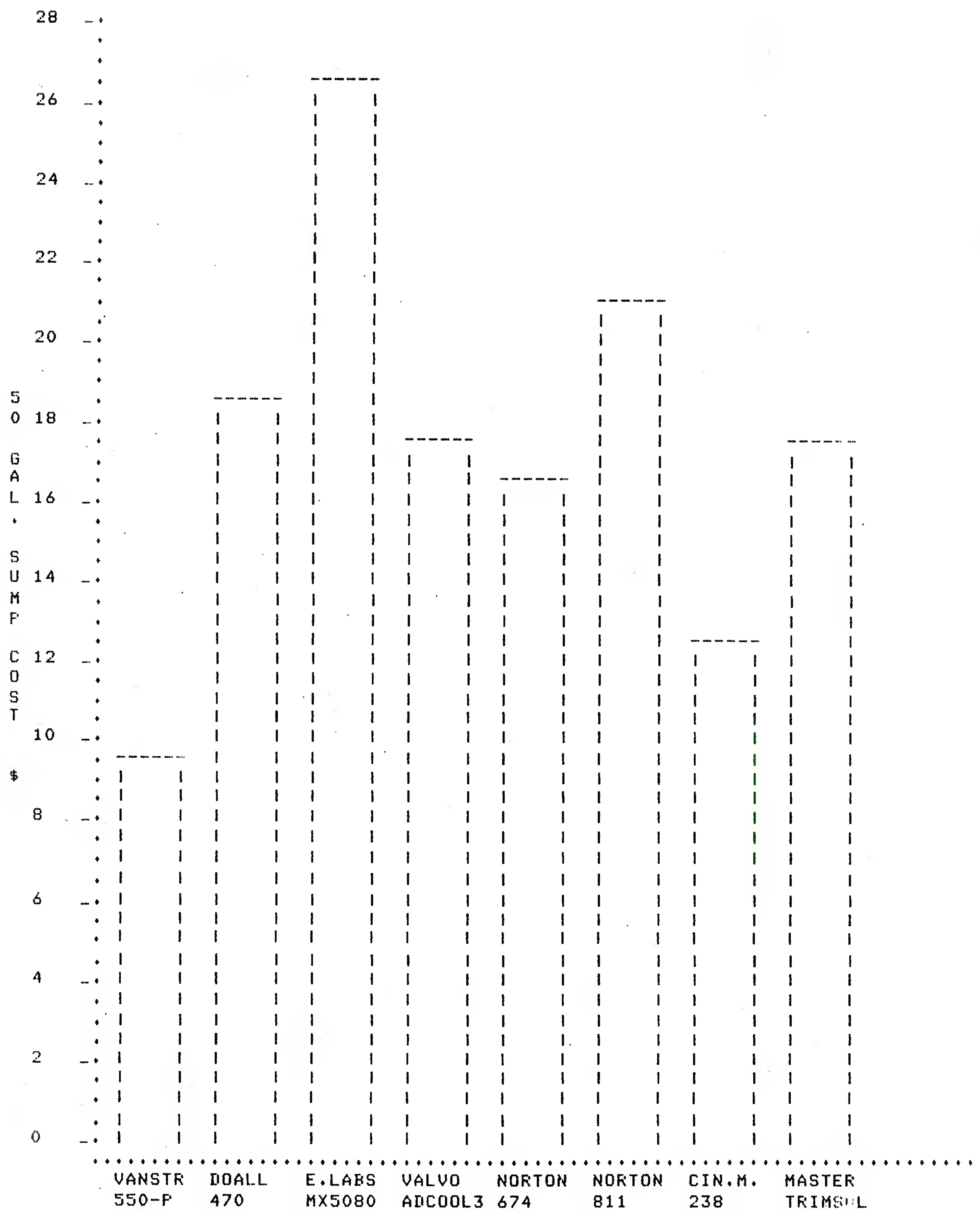


Figure 3.5-7. Price to Fill a 50 Gallon Sump vs Turning Fluids Tested.

Another factor that affects turning performance is cutting fluid flow. A twenty-seven percent decrease in cubic inches of metal removed was observed during a test conducted with a slight reduction in fluid flow (see Figure 3.5-8). A linear regression comparing the two tests are displayed in Figure 3.5-9. Notice the difference in slopes or flank wear rates of the two tests. These results strongly underscore the importance of fluid delivery rates to the cutting zone.

3.6 Milling

The milling section will review the basics of milling, describe the manufacturing procedures observed at RIA, review Machining Technology's testing procedures and review the results of these tests. These subjects are presented in the following subsections: review of the basics of milling, RIA milling survey, milling cutting fluid test selection, milling test design, Machining Technology's test conditions, milling test results and conclusions.

3.6.1 Review of the Basics of Milling

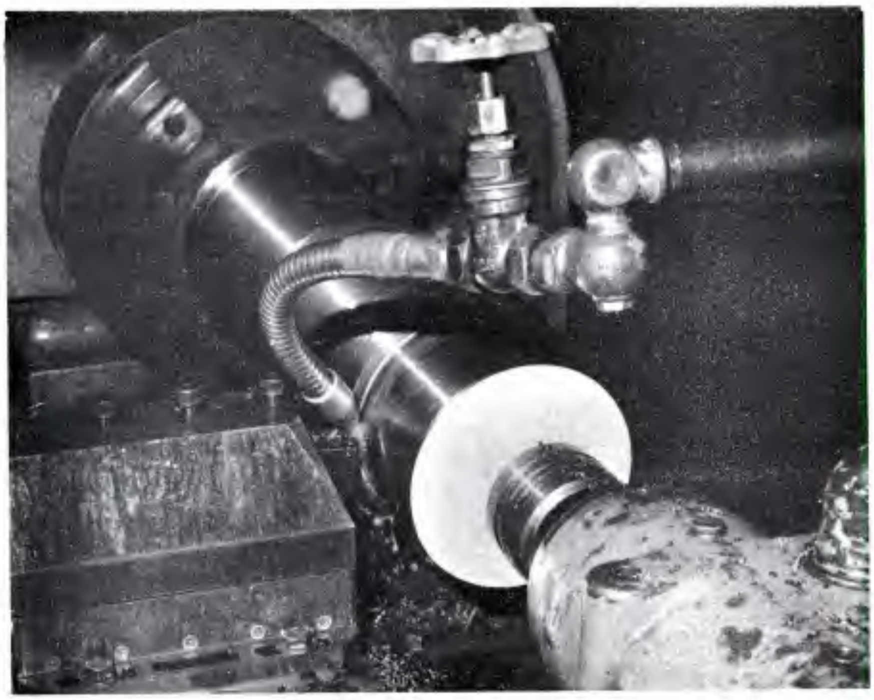
Milling generates a machined surface through progressively removing material from a workpiece utilizing a single or multiple tooth cutter. This operation involves the relative motions between a rotating cutter and an independently moving workpiece. There are three basic types of milling: peripheral milling, face milling and end milling (see Figure 3.6-1).

Peripheral milling or slab milling utilizes a milling cutter that contains its cutting teeth on the outside of the periphery and in many cases parallel to the main cutter axis. Operations using formed or shaped cutters are usually done by peripheral milling. Peripheral milling is usually accomplished using a milling machine with a horizontal-axis. However, it also may be performed using the circumferential cutting edges of an end mill. The process of face milling uses two different cutting edges to create a machined surface. The periphery of the individual teeth remove most of the metal, while the face-cutting edges machine the finish of the newly generated surface. A face milling cutter axis is perpendicular to the workpiece surface. End milling can be a type of peripheral milling or face milling. An end mill's axis is perpendicular to the workpiece surface.

There is another basic distinction made in milling which has to do with the direction from which the cutter approaches the workpiece. The workpiece can be fed either with or against the direction of cutter rotation. When the cutter rotates in the feed direction, the technique is called down milling or climb milling (see Figure 3.6-2). Up milling is sometimes called conventional milling.

There are three parameters that are important in milling: cutter speed, feed rate and depth of cut (DOC). There are two methods of measuring cutter speed. The first is rotational speed or revolutions per minute (RPM). This is the count of the number of times that a rotating object makes a complete revolution around the spindle axis in a minute. However, this is not an accurate method of describing the cutter dynamics of milling because the peripheral cutting speed of an individual milling cutter varies with its diameter. Cutting speed is measured in surface feet per minute (SFM)

High Flow



Low Flow

Figure 3.5-8. Pictures of Tests run at two Different Fluid Flow Rates.

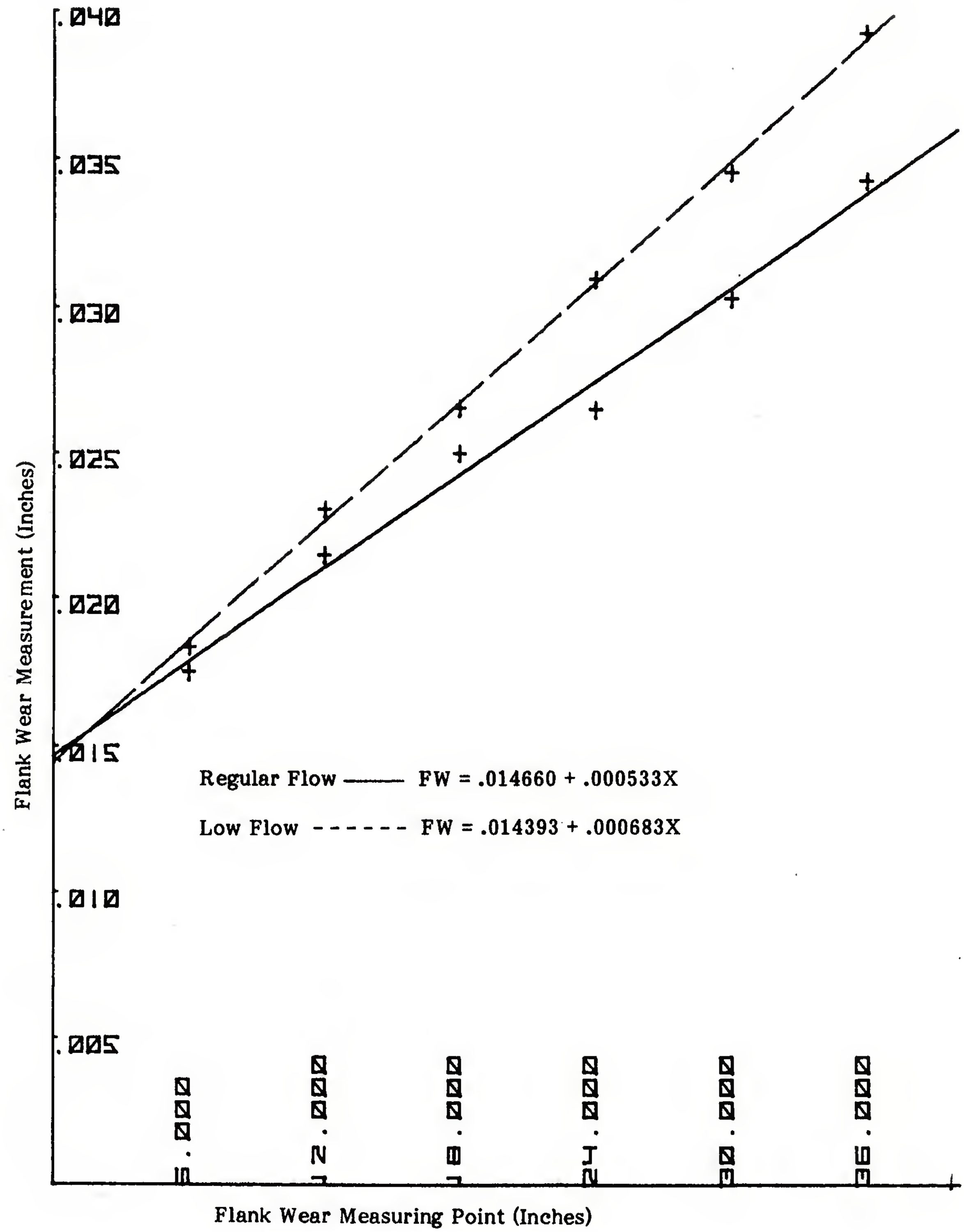


Figure 3.5-9. Linear Regressions Comparing Regular Flow to Low Flow.

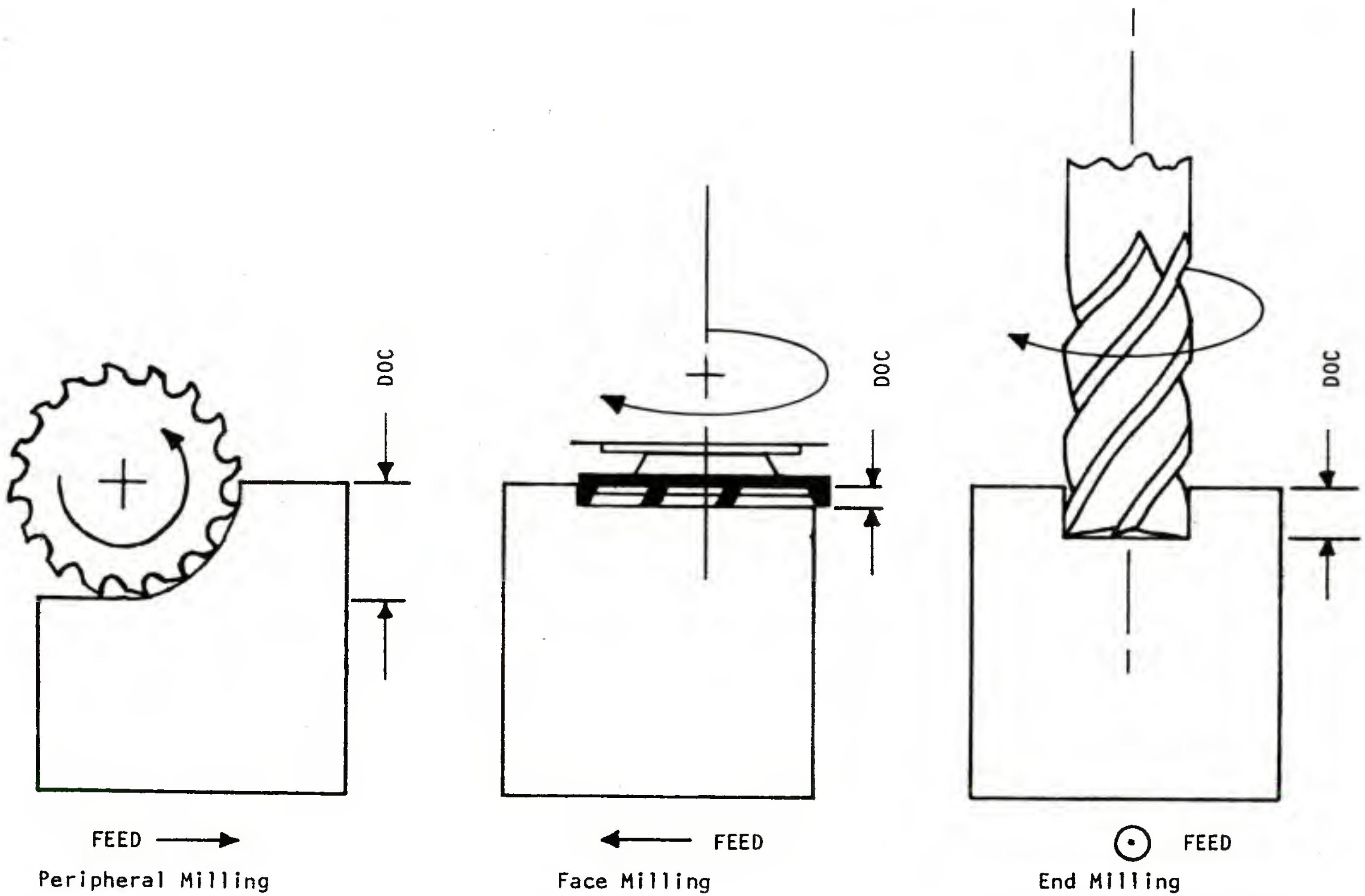


Figure 3.6-1. An Illustration of the Basic Types of Milling.

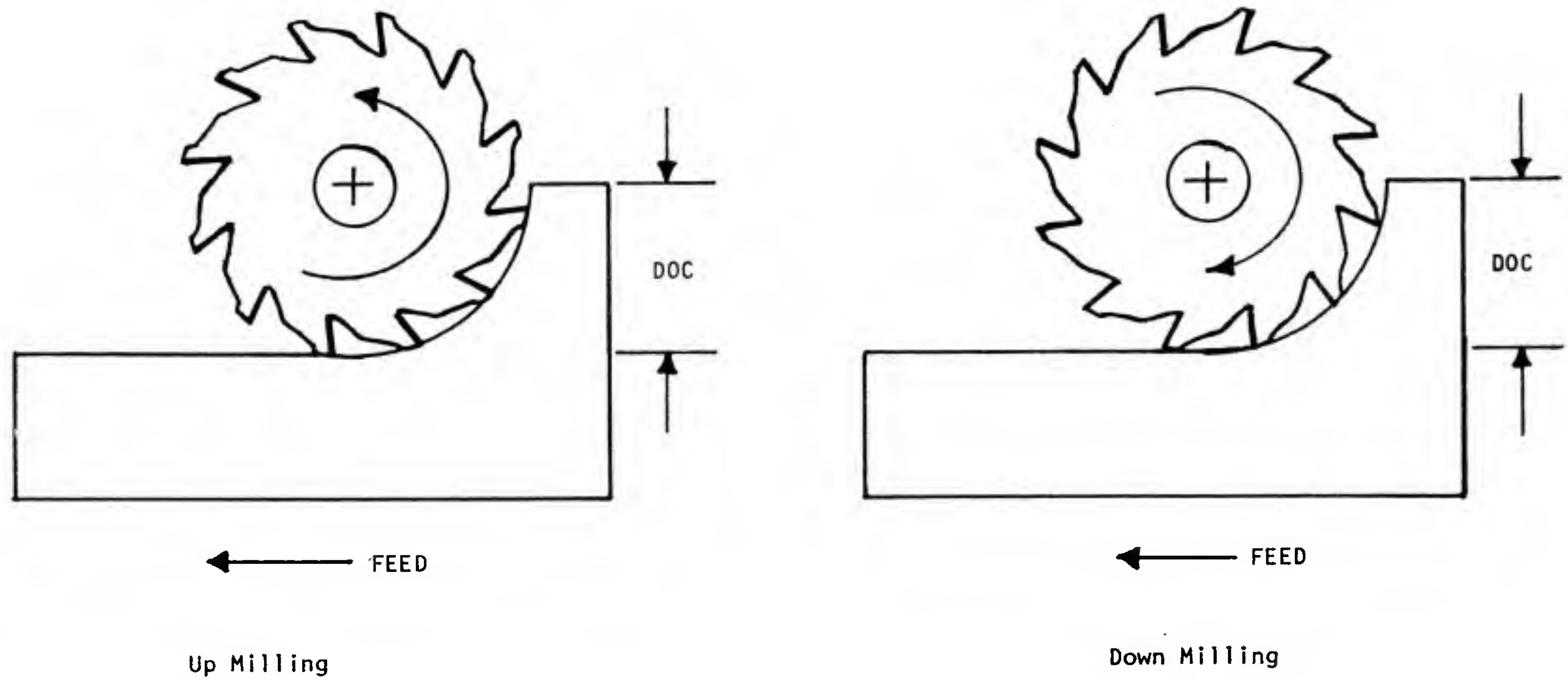


Figure 3.6-2. An Illustration of Up and Down Milling.

which is a measure of the actual velocity of a cutting tooth passing across the stationary workpiece. The formula for calculating SFM appears below:

$$\text{SFM} = (.262) \times \underset{\text{in inches}}{(\text{Cutter diameter})} \times (\text{RPM})$$

Milling feed is a combination of the machine's feedrate, the cutter diameter and the number of teeth on the cutter which is called the feed per tooth (F.P.T.). The feed per tooth is calculated in the formula below:

$$\text{F.P.T.} = \frac{\text{Machine Table Speed in inches per minute}}{\text{Number of cutter teeth} \times \text{RPM}}$$

The depth of cut (DOC) is how deep the cutter penetrates the workpiece (see Figure 3.6-1).

Other factors, such as material type, material hardness and tool selection, also influence the milling operation. These factors are the same as turning and are covered in Section 3.5-1. Also, the same cutting fluid properties should be utilized as in turning. These properties are displayed in Section 3.5-1.

3.6.2 RIA Milling Survey

A portion of the following represents a reiteration of Sections 3.1 and 3.2. It is presented again here to add continuity to this discussion and allow this section to be complete in itself.

Milling operations at RIA can be placed in three basic categories: face, end, and peripheral milling. These operations are performed on either N/C or conventional machine tools. The N/C equipment was operated at speed ranges of 400-700 SFM, somewhat higher than the 100-350 SFM range of the conventional machines. Many of the face milling operations were performed without the use of a cutting fluid. All of the milling operations are displayed in Table 3.2-3.

All of the observed tool wear was in the form of chipping (see Table 3.1-3). An example of a chipped milling cutter may be observed in Figure 3.1-7. Notice how minimal the other forms of tool wear are in comparison to the microfracturing of the cutting edge. This mode of tool failure can be caused by using a slower surface speed than for which the cutting tool was designed. Another reason could be a lack of rigidity in the setup. The most probable cause of chipping is insufficient cooling or lack of lubrication at the tool/workpiece interface. This condition may be caused by applying cutting fluids to the tool/workpiece interface in insufficient quantities, using an inadequate cutting fluid for the machining operation or utilizing a cutting fluid below its recommended concentration level. All of the N/C milling equipment seemed to provide adequate cutting fluid flow on the tool and workpiece. However, many of the older milling machines in Shop M had minimal fluid flow and, in some cases, operations were run dry. Many operations were observed having lower than recommended cutting fluid concentration levels.

3.6.3 Milling Test Fluid Selection

Initially, all three generic types of cutting fluids were to be tested and compared to a base cutting fluid without E.P. additives. The base fluid is number one in Table 3.6-1 and the initial test fluids are numbered two through four. All of the initial test fluids were considered medium to heavy duty except number one. Fluid number two was selected as the emulsion test fluid because it is currently being used at RIA. Fluid number three was chosen as the full synthetic test fluid because past tests have proven it to be effective and economically superior. Also, it is currently used at RIA. The semi-synthetic fluid number four was chosen because of its past performance record in turning.

After initial evaluations, additional products were tested, full synthetic fluid number five was tested because it contained similar properties to test fluid one, which was showing superior performance. Test fluid six was selected because of the results of test fluid four, showing that a semi-synthetic performed well. Both fluids were semi-synthetics with number six having a much lower 50 gallon sump cost.

3.6.4 Milling Test Design

All of the milling tests were conducted at the severest milling parameters used at RIA. These test parameters are as follows:

Tooling:	Valenite MSN75-168-4R3-125, end mill tool holder Valenite SNEA-432, VC-55 carbide insert
SFM:	660
Chipload:	.003 inches/tooth
Feed:	4.625 inches/min.
Cutter Diameter:	1.680 inches
Depth of Cut:	.050 inches
Material:	4140 steel
Fluid Application:	Single pipe at a flow rate of 2 gallons per minute
Test Run Criteria:	Each test was run until .010 inches of flank wear was observed.

3.6.5 Test Conditions

All of the tests were performed on a Kearney & Tecker Model SHP-2CH mill located in the Machining Research Laboratory of the Colwell Engineering Center. The test arrangement is shown in Figure 3.6-3 which illustrates the relationship of the cutting tool to the workpiece and the cutting fluid application system. The workpiece was mounted on a Kristal Instrument piezoelectric machining dynamometer which permitted evaluation of the three orthogonal forces generated while cutting (see Figure 3.6-4). The output signals from the dynamometer were recorded in analog form on a Honeywell 1858 visicorder oscillograph. The signal data were later reduced to digital

TABLE 3.6-1

MILLING FLUIDS SELECTED FOR TESTING

Fluid #	Fluid	Manufacturer	Type	Strength	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	470	DoAll	E	LD				$18.40
2*	Trimsol	Master Chemical	E	HD	C			$17.25
3*	Cimfree 238	Cincinnati Milacron	FS	HD			++	$12.50
4	674	Norton	SS	HD		S		$16.50
5	Adcool-2	Valvoline	FS	LD-MD			+	$10.65
6	550-P	Van Straaten	SS	MD	C			$ 9.33

Key:

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic
LD = Light Duty
HD = Heavy Duty
MD = Medium Duty

C = Chlorine
S = Sulfur
+ = Others
* = Currently Used at RIA

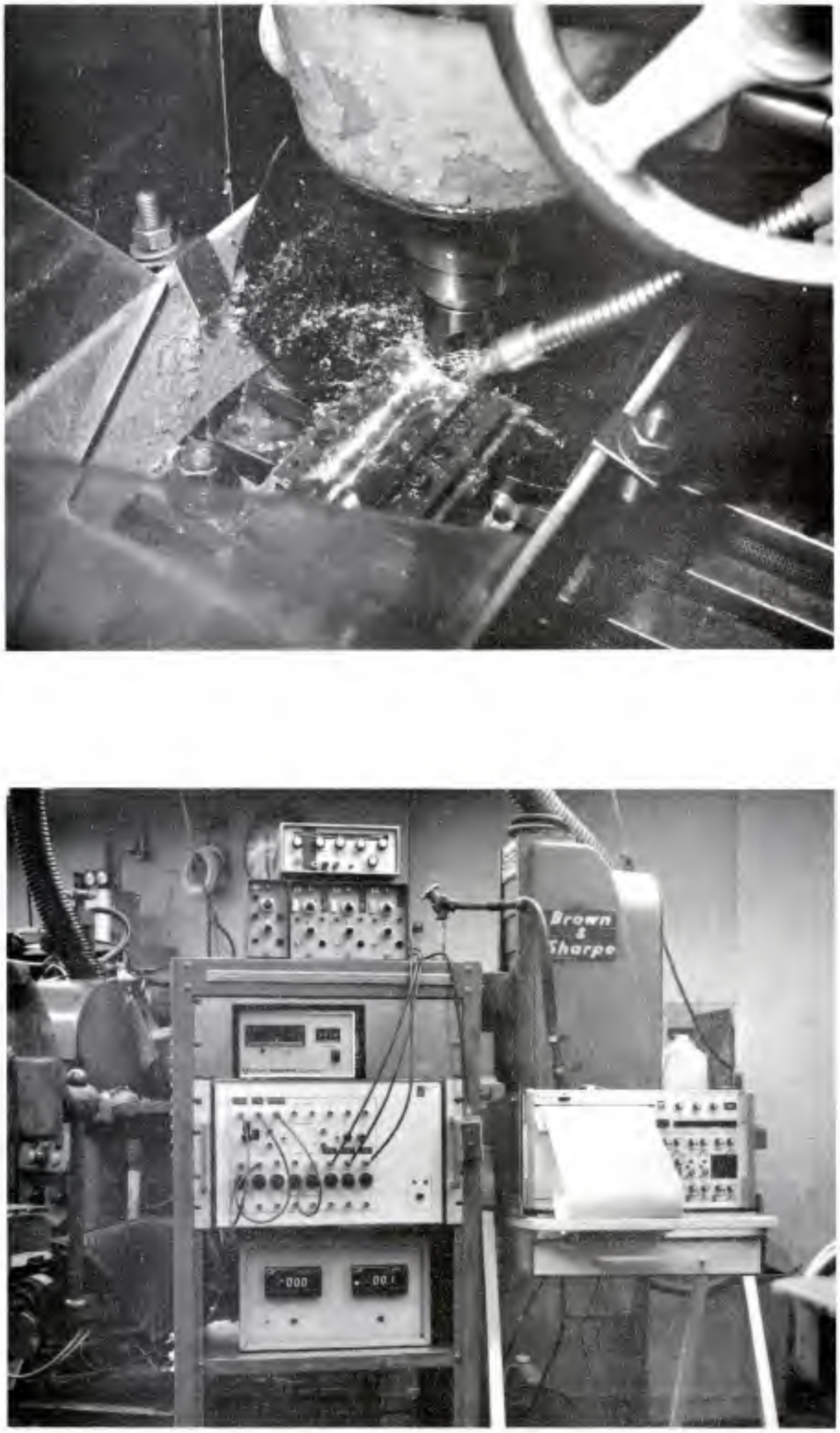


Figure 3.6-3. A Photograph of the Milling Testing Arrangement.

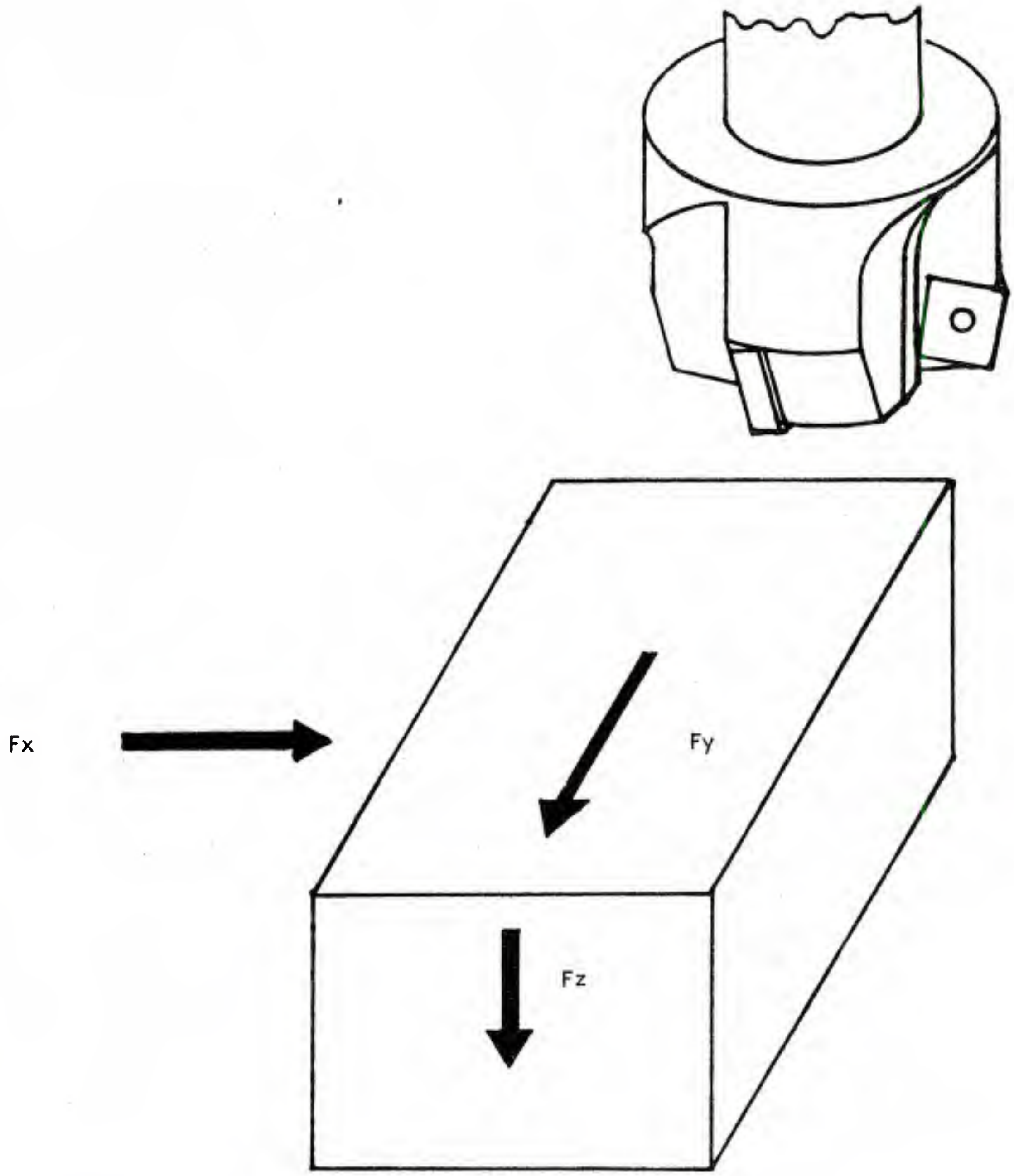


Figure 3.6-4. An Illustration of the Dynamometer Cutting Forces Measured.

values employing sensor calibration factors and measuring the signal trace deflection at the point of interest within the machining event. Tool wear measurements were ascertained utilizing a Gaertner toolmaker's microscope. In keeping with the majority of metal cutting research work, tool wear was defined as the maximum length of wear pattern observed in the tool flank face.

3.6.6 Milling Test Results

The milling was accomplished using a single carbide insert in a 1.68 inch diameter milling cutter body. Flank wear was measured after milling the full length of a 1.8" x 6" x 4" test block. Each test was continued until at least .010 of an inch of flank wear was observed. Linear regressions were performed on these data. A sample linear regression is displayed in Figure 3.6.5 for fluid number one. The linear regressions were plotted using six or seven flank wear observations, depending on the test's tool wear rate. Using the average of all the test intercepts to calculate the amount of material removed to .010 inches of flank wear, as described in the turning and boring section 3.5.6, was again used in milling. Portions of Section 3.5.6 will be reiterated to maintain continuity. Figure 3.6-5 illustrates the basic two-part form of the linear regression for fluid number 1: the slope (.00022) and the intercept (.001071).

The steady state condition which occurs after the tool's initial break-in and before catastrophic failure is described by the slope. This steady state condition takes on a linear relationship that describes the development of the tool's wear scar. The slope may be used to compare the relative performances of cutting fluids. Good cutting fluids will have a lower slope, poorer cutting fluids will have a steeper slopes.

The intercept, in general, is the extrapolation of data back to a zero point. In the case of the cutting fluid tests, the intercept represents the point just before initial tool wear contact. Initially, the tool wear process proceeds at an extremely rapid rate until the tool "breaks in". The intercept takes into account the initial cutting edge of the tool during "break in", which describes the initial condition of the cutting edge from the manufacturer and a slight contribution of the cutting fluid.

The amount of metal removed to reach .010 of an inch of flank wear was calculated for each test fluid using the linear regression analysis data. An average value was used for the intercept when calculating these values because its value is directly influenced by the initial cutting edge of individual tools which are subject to some variation. This will allow all of the test fluids to be compared from the same initial starting point.

Force data were also collected during each six-inch milling pass. Six or seven data points were averaged for each test fluid, depending on when the tool reached .010 of an inch of flank wear. The force values were measured at the end of each six-inch milling pass.

The results of these analyses were displayed in Table 3.6-2. Also, no excessive flank wear or chipping was observed during the tests or the SEM evaluations.

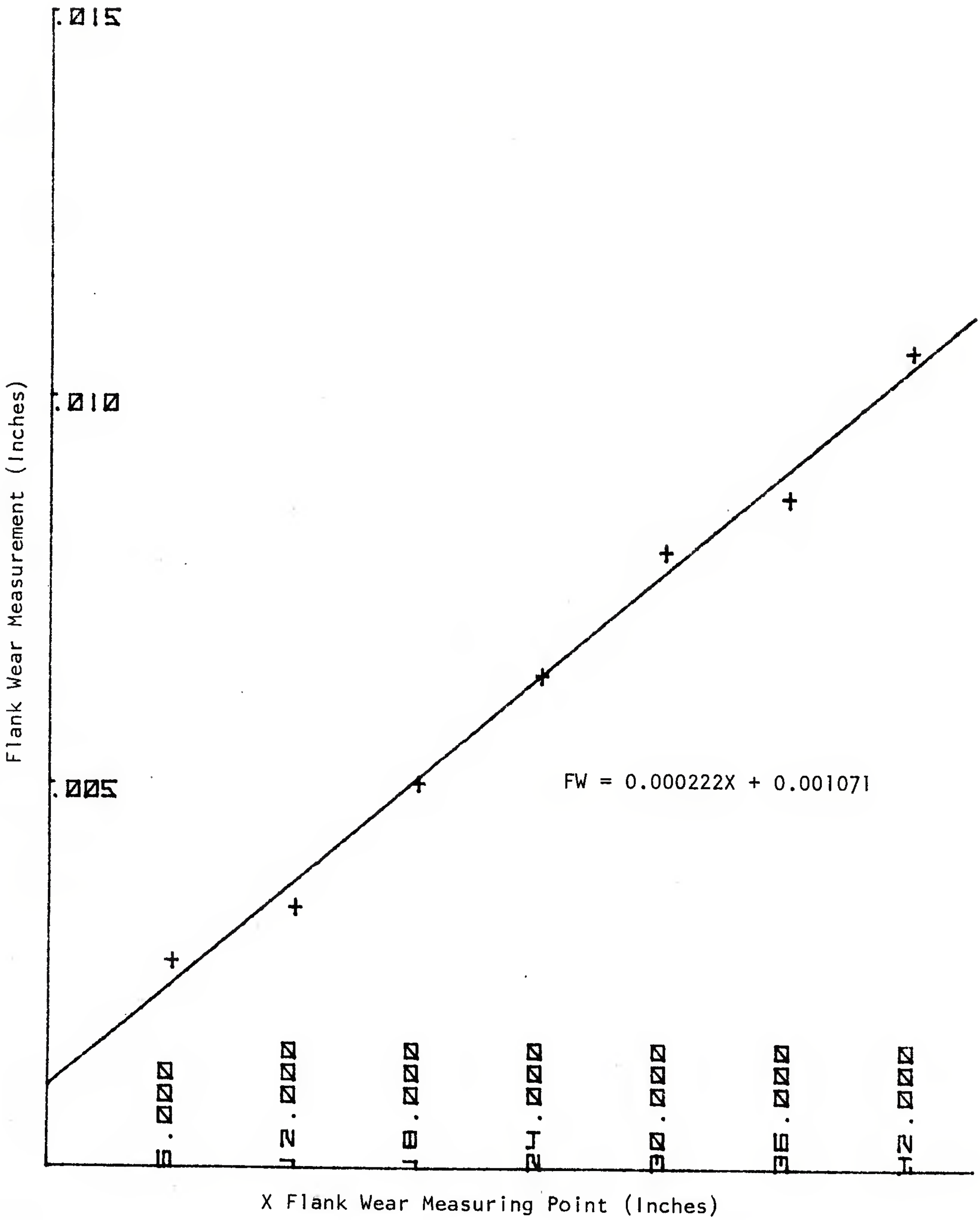


Figure 3.6-5. A Linear Regression for Fluid Number One.

TABLE 3.6-2

MILLING TEST RESULTS

Fluid Number	Fluid	Manufacturer	Linear Scope	Regression Intercept	IN^3 Removed	AVG F(x) (Lbs)	AVG F(z) (lbs)
1	470	DoAll	.000222	.001071	3.31	97.75	38.80
2	Trimsol	Master Chemical	.000251	.000747	2.93	98.87	44.75
3	Cimfree 238	Cin. Milacron	.000232	.001853	3.17	102.56	45.70
4	674	Norton	.000236	.001173	3.12	99.52	43.40
5	Adcool-2	Valvoline	.000275	.001280	2.68	100.32	46.92
6	550-P	Van Straaten	.000243	.001333	3.03	97.27	38.00

3.6.7 Milling Conclusion

Two histogram graphs were computed from data displayed in Table 3.6-2. The first graph is presented in Figure 3.6-6 and shows the cubic inches of material removed when the cutting tool used with that fluid reached .010 of an inch of flank wear. Also, each cutting fluid was compared by percentage of increased tool life to test fluid number five, which had the lowest performance of the fluids tested (see Figure 3.6-7). The graphs indicate that the fluids performed almost equally. A maximum difference in performance of only 24% was observed. The two top performers were DoAll's 470 and Cincinnati Milacron's Cimfree 238. Both of these fluids do not contain sulfur and/or chlorine E.P. additives.

The milling operation with the interrupted cut does not generate enough heat to produce the chemical reaction required to release these additives. When this condition exists, fluids containing natural oil or oil-like lubrication properties without chlorine and/or sulfur E.P. additives provide a slight increase in milling performance.

The fifty gallon sump cost for each of these fluids is displayed in Figure 3.6-8. The economics of the fluid is very important in milling due to the closeness of the performance data of all the cutting fluids tested. The fluid that shows high performance and has a low sump cost is Cincinnati Milacron's 238. The lower sump cost and the potentially longer sump life of a full synthetic fluid may outweigh the additional six percent increase in milling performance DoAll's Wheelmate 470 offers. The DoAll Wheelmate 470 has the highest fifty gallon sump cost which is almost $6.00 higher than Cimfree 238's. A careful economic analysis must be made before a milling cutting fluid can be selected. Another governing factor in selecting the milling cutting fluid is what fluid would be superior for grinding, turning, and boring. The performance increase between the optimal grinding, turning and boring fluid and the optimal milling fluid may not warrant the increase logistics cost for maintaining an additional cutting fluid.

3.7 Drilling and Tapping

The drilling section will review the basics of drilling, describe the manufacturing procedures observed at RIA, review Machining Technology's testing procedures and review the results of these tests. These subjects are presented in the following subsections: review of the basics of drilling, RIA drilling survey, drilling cutting fluid test selection, drilling test design, Machining Technology's test conditions, drilling rest results and conclusions.

The tapping operation will not be addressed in this phase of the program. Currently, fluids are being examined that may be applicable for both turning and tapping operations. However, additional data must be developed. The current tapping material, Johnston's tapping wax, is performing adequately for the modest amount of tapping that was observed being done at RIA.

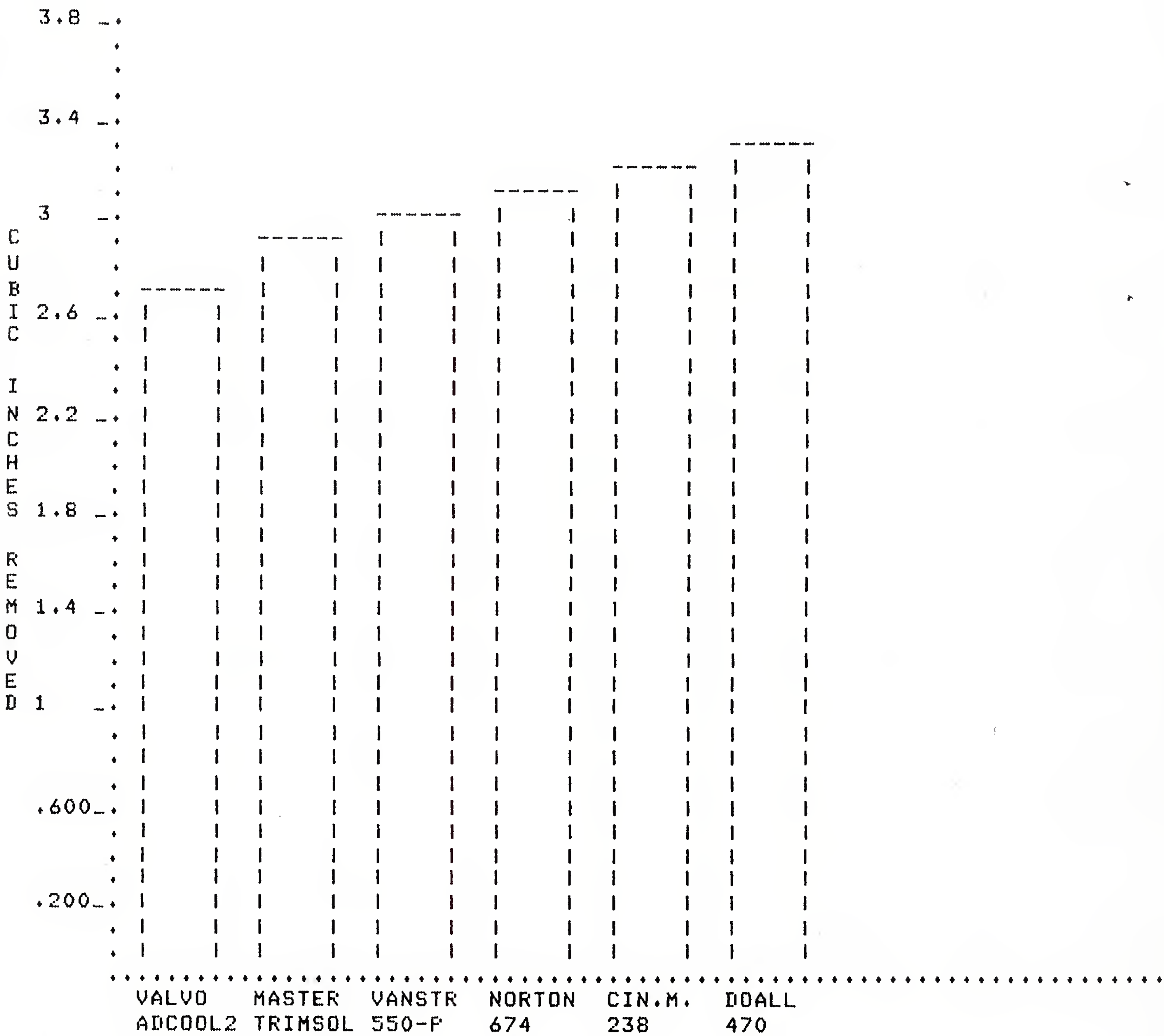


Figure 3.6-6. Cubic Inches of Metal Removed to .010 of an inch of Flank Wear vs Milling Fluids Tested.

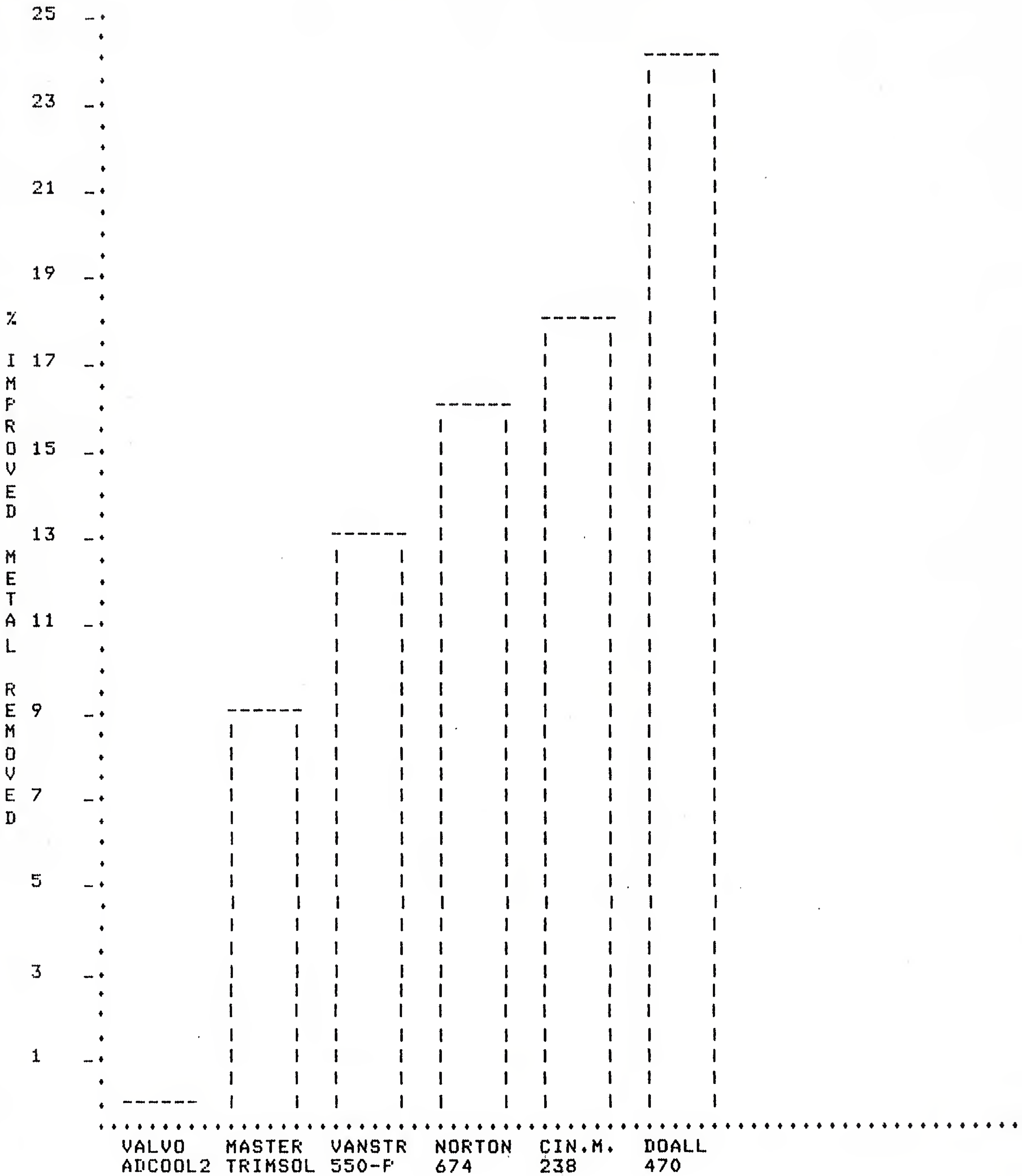


Figure 3.6-7. Percent Improved Tool Life Compared to Adcool-2.

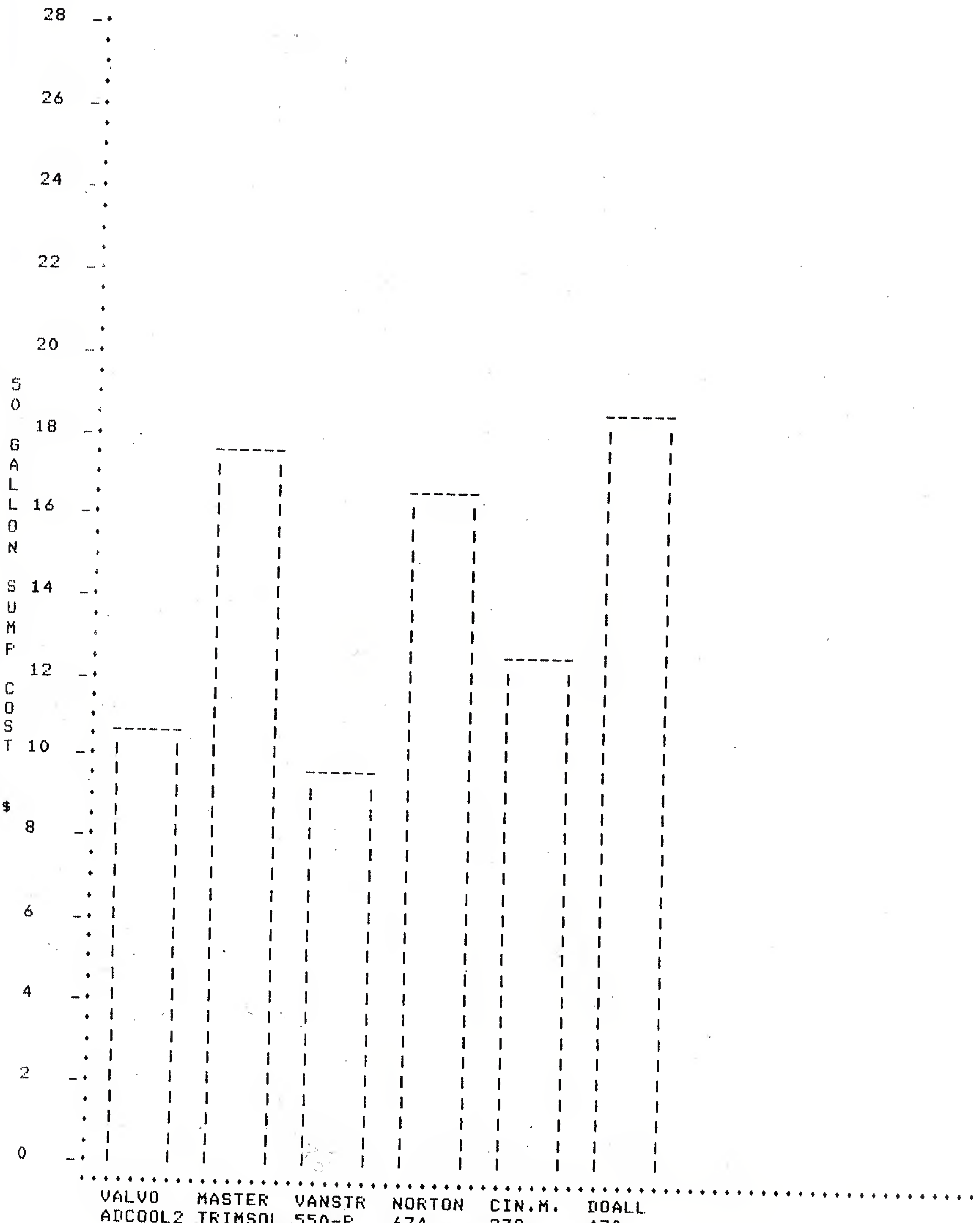


Figure 3.6-8. Price to Fill a 50 Gallon Sump vs Milling Fluids Tested.

3.7.1 Review of the Basics of Drilling

During the drilling process cutting occurs on the straight edges (lips) and on the chisel edge at the tip of the drill. The web which is the distance between the straight cutting edges is necessary to protect the drill point and stiffen the drill. The chips created at the cutting edges travel up the axis of the drill along the flutes. All of the drill's cutting is accomplished on the periphery, except near the outer corner, which is like an end cutting edge of a lathe tool. The drill diameter is decreased over a portion of its circumference leaving a short land or margin at the full diameter to support the drill against the hole. This reduces the frictional forces between the drill and the hole. Also, the diameter along the length of the drill is slightly reduced towards the shank to give it further clearance. The point angle is like the side cutting edge of a lathe tool. It gives the drill gradual entry into the work, influences the chip-flow direction and alters the forces on the cutting edges. Figure 3.7-1 illustrates the parts of a standard twist drill.

There are three main parameters used in drilling: speed, feed rate and aspect ratio, or hole depth in relation to its diameter. The speed of a drill is measured by the rate the periphery of the tool moves in relation to the workpiece. The common term for this is surface feed per minute (SFM). The formula to calculate SFM is displayed below.

$$SFM = .262 \times RPM \times \text{Drill Diameter in Inches}$$

Drilling feed rates are governed by the size of the drill, machineability of the material being used and the depth of hole. Small drills, hard material and hole depths in excess of 3-4 drill diameters require additional consideration in selecting feed rates because these conditions make drilling more difficult. The feed rate is measured in inches per revolution. The hole depth is the distance the hole is drilled.

The cutting fluid used in a drilling operation should possess the following qualities: it should first lubricate the contact surfaces between the tool and the work. This will reduce friction which will reduce the heat generated. Also, the fluid should lubricate the chip and the top surface of the drill. This will prevent the chips from sticking to the drill. The cooling ability is an important property of a drilling fluid. The fluid should have the ability to carry away heat at the same rate it is generated. This also emphasizes the need for a copious fluid flow in a drilling operation. Chip disposal is another important cutting fluid function. Other factors, such as rust prevention, bacteria control, mold control and operator acceptance, should be considered.

3.7.2 RIA Drilling Survey

It is apparent from the RIA Manufacturing Process Data Analysis Sheet for Drilling (see Figure 3.2-4) that all of the drilling operations were conducted at common parameters. Most of the holes had aspect ratios in the two to three range with one

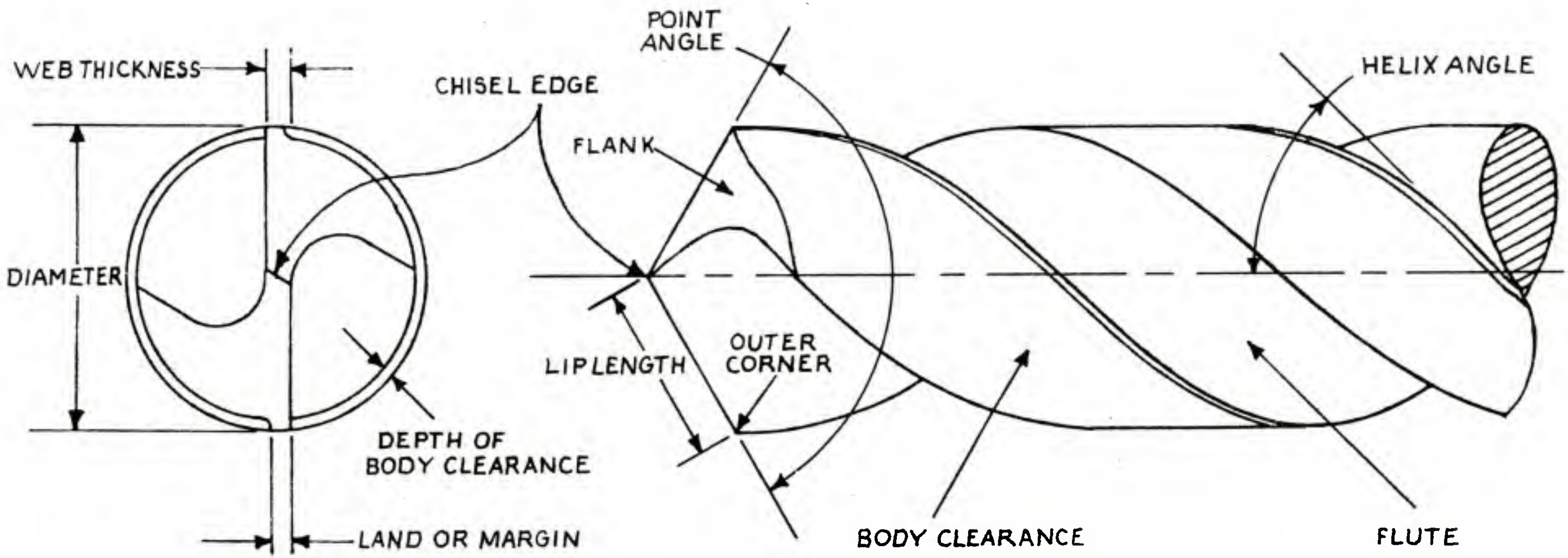


Figure 3.7-1. An Illustration of a Twist Drill.

exception. Observations of worn drills at RIA indicated operators removed drills from service prior to experiencing catastrophic damage to the drill point, a desirable condition.

3.7.3 Drilling Test Fluid Selection

Initially, all three generic types of cutting fluids were to be tested and compared to a base cutting fluid without E.P. additives. The base fluid is number one in Table 3.7-1 and the initial test fluids are numbered two through four. All of the initial test fluids were considered medium to heavy duty except number one. Fluid number two was selected as the representative emulsion test fluid because it is currently being used at RIA. Fluid number three was chosen as the full synthetic test fluid because past tests have proven it to be effective and economically superior. Also, it is being used at RIA. The semi-synthetic fluid number four was selected because of its past performance record in turning.

After initial tests, full synthetic fluid number five was tested because it contained similar properties to test fluid three which was demonstrating superior performance.

3.7.4 Drilling Test Design

All of the drilling tests were conducted at the severest drilling parameters used at RIA. These test parameters are as follows:

Tooling:	.250 inch Union Twist Drills, List 236 BLUE, 41-10154
SFM:	60 ft/min
Chipload:	.027 inches/revolution
Feed:	3.300 inches/min
Depth of Hole:	.500 inches
Material:	4140 Steel
Fluid Application:	Single pipe at a flow rate of 2 gallons per minute
Test Run Criteria:	Fifteen holes were drilled for each test. Flank wear measurements were taken after every fifth hole.

3.7.5 Test Conditions

All of the tests were performed on a Kearney & Trecker Model SHP-2CH mill located in the Machining Research Laboratory of the Colwell Engineering Center. The test arrangement is shown in Figure 3.7-2, which illustrates the relationship of the drill to the workpiece and the cutting fluid application system. The workpiece was mounted on a Kristal Instrument piezoelectric machining dynamometer which permitted evaluation of the two forces generated while drilling (see Figure 3.7-3): the normal force and the drill torque. The output signals from the dynamometer were recorded in

TABLE 3.7-1

DRILLING FLUIDS SELECTED FOR TESTING

Fluid #	Fluid	Manufacturer	Type	Strength	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	470	DoAll	E	LD				$18.40
2*	Trimsol	Master Chemical	E	HD	C			$17.25
3*	Cimfree 238	Cin. Milacron	FS	HD			++	$12.50
4	674	Norton	SS	HD		S		$16.50
5	Adcool-2	Valvoline	FS	LD-MD			+	$10.65

Key:

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic
LD = Light Duty
HD = Heavy Duty
MD = Medium Duty

C = Chlorine
S = Sulfur
+ = Others
* = Currently Used at RIA

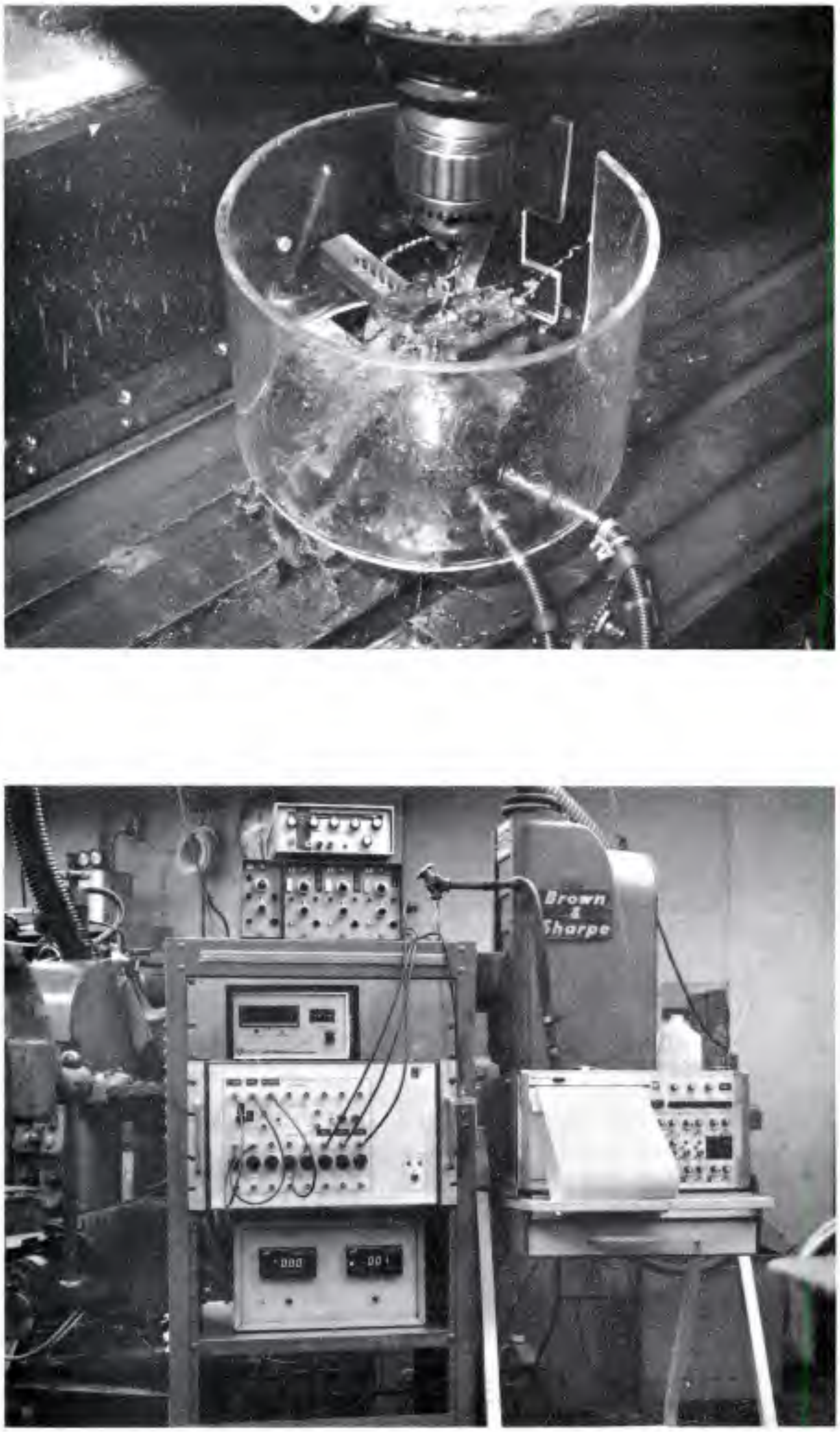


Figure 3.7-2. Photographs of the Drilling Test Arrangement.

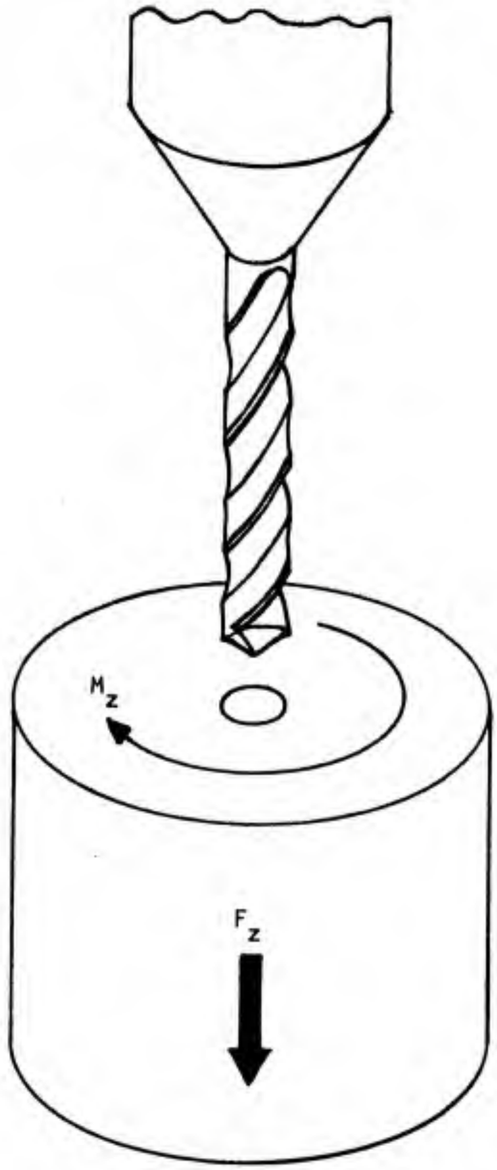


Figure 3.7-3. An Illustration of the Dynamometer Forces Measured.

analog form on a Honeywell 1858 visicorder oscillograph. The signal data was later reduced to digital values employing sensor calibration factors and measuring the signal trace deflection at the point of interest within the machining event. Tool wear measurements were ascertained utilizing photographs of the test tools. These pictures were taken at 12X. Spindle power was not recorded because the mill's spindle motor also operated the head and table drives. Such a condition would given inaccurate power readings.

3.7.6 Drilling Test Results

The drilling was accomplished using a standard one-quarter inch drill which drilled through a one-half inch metal plate fifteen times. During the drilling of each hole force measurements were taken for the drilling torque and the normal force. The force measurements used for comparison were taken at the end of the fifteenth hole. Also, tool wear was observed under a Gaertner toolmaker's microscope after every fifth hole drilled. Pictures of the test drills were taken after the fifteenth hole was drilled under 12X magnification for every test (see Figures 3.7-4 through 3.7-8). The force data and comments on the observed drill wear is displayed in Table 3.7-2.

3.7.7 Drilling Test Conclusions

Two histogram graphs were computed from the data displayed in Table 3.7-2. The first graph is presented in Figure 3.7-9 which shows the torque around the drill that no cutting fluid displayed a marked torque performance increase over all the fluids tested. However, Figure 3.7-10 displays a histogram graph of the normal (Fz) forces. Here there is as much as 28% difference between force levels. These differences are further detailed by Figure 3.7-11 which graphs all of the fluids tested compared to Trimsol which produced the highest Fz test force. The graph presents the percent tools under 12X magnification supports the distribution displayed in Fz force graph in Figure 3.7-10. Both Cincinnati's Cimfree 238 and Norton's Wheelmate 674 displayed less point wear than the other three fluids tested. Another factor to consider is the fifty gallon sump price for each fluid. Cincinnati Milacron's Cimfree 238 has the lowest cost of the high performing fluids (see Figure 3.7-12).

3.8 Broaching

This section will review the basics of broaching, describe the processes observed at RIA, and discuss the results of the evaluation conducted.

3.8.1 Review of the Basics of Broaching

Broaching is an operation used to cut forms in metal workpieces with multi-toothed cutters. Many types of broaches are presently in use, but all have several common features. First, the broach tools themselves usually have complicated geometries. This results in difficult, time consuming resharpenings. Thus broaching is cost effective only for large lots of parts where the life of the broach tool can be fully utilized. Secondly, the cutting speeds used on broaches are relatively low, usually

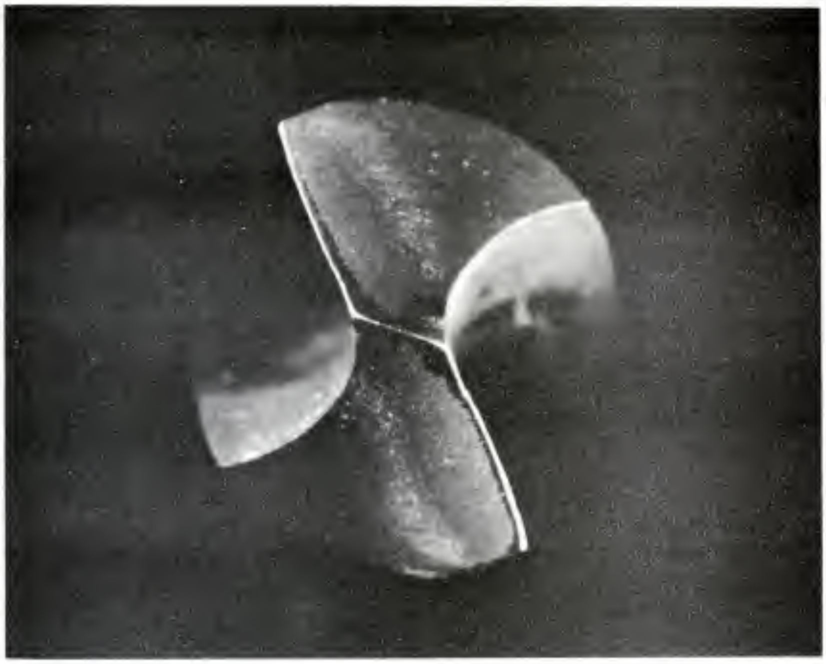


Figure 3.7-4. A Drill Tested With Cincinnati Milacron's Cimfree 238.

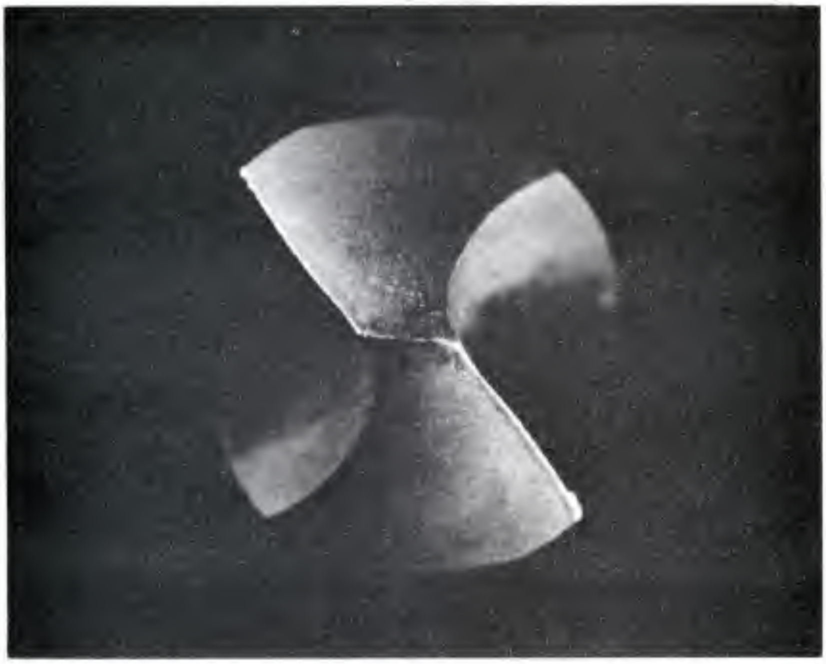


Figure 3.7-5. A Drill Tested With Norton's Wheelmate 674.

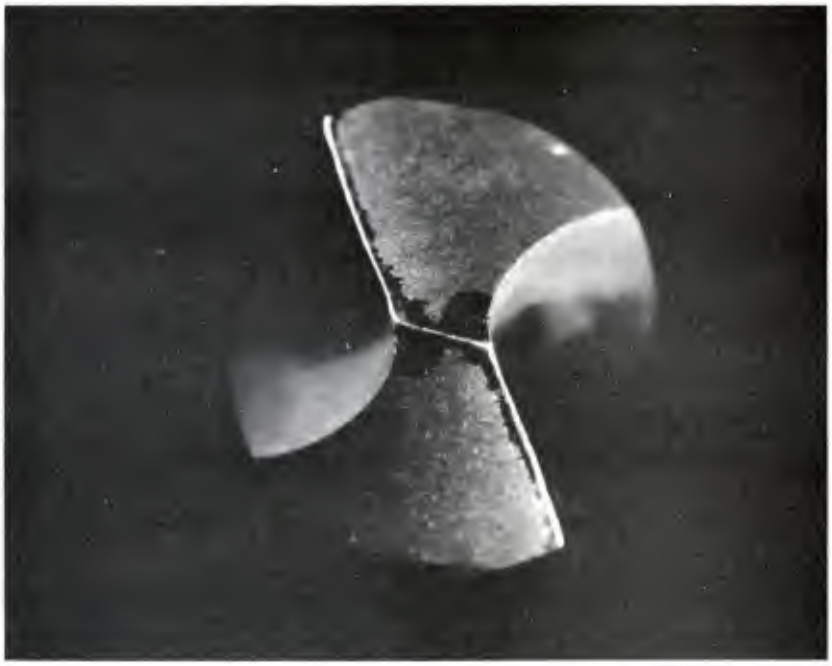


Figure 3.7-6. A Drill Tested With Master Chemical's Trimsol.

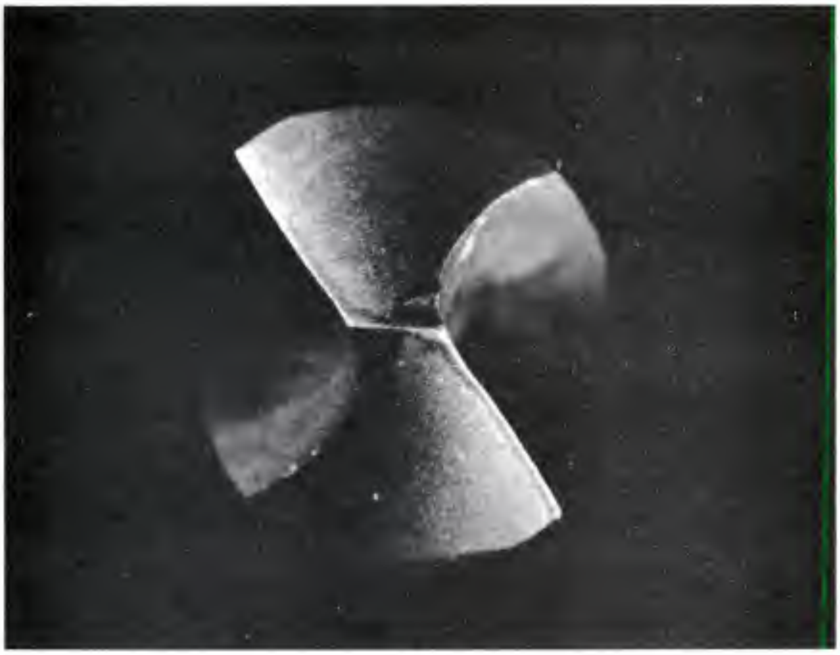


Figure 3.7-7. A Drill Tested With DoAll's 470.

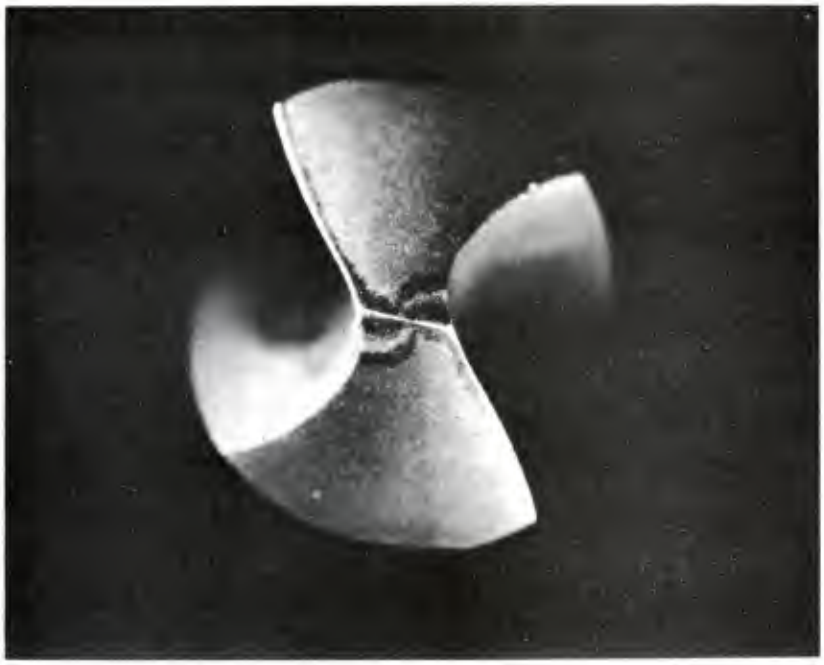


Figure 3.7-8. A Drill Tested With Valvoline Oil's Adcool-2.

TABLE 3.7-2

DRILLING TEST RESULTS

Fluid	Fluid	Manufacturer	Fz(lbs)	Mz(Ft-Lbs)	12X Picture Observations
1	470	DoAll	17.50	2.78	Some point wear, no BUE Slight stain on point & margin
2	Trimsol	Master Chemical	17.60	2.84	Some point wear, no BUE Heavy stain on point & margin
3	Cimfree 238	Cin. Milacron	13.70	2.90	Very slight wear, no BUE Heavy stain on point & margin
4	674	Norton	15.60	2.70	Very slight wear, BUE Slight stain on point & margin
5	Adcool-2	Valvoline	17.30	2.66	Some point wear, no BUE Slight stain on point & margin

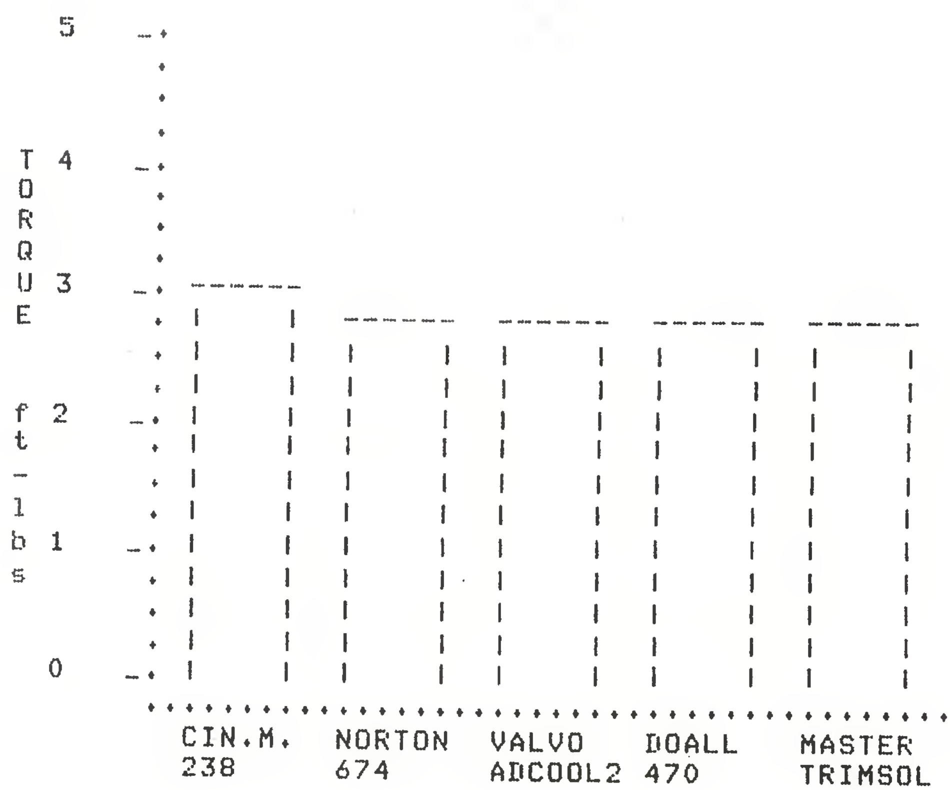


Figure 3.7-9. Drill Axis Torque vs Drilling Fluids Tested.

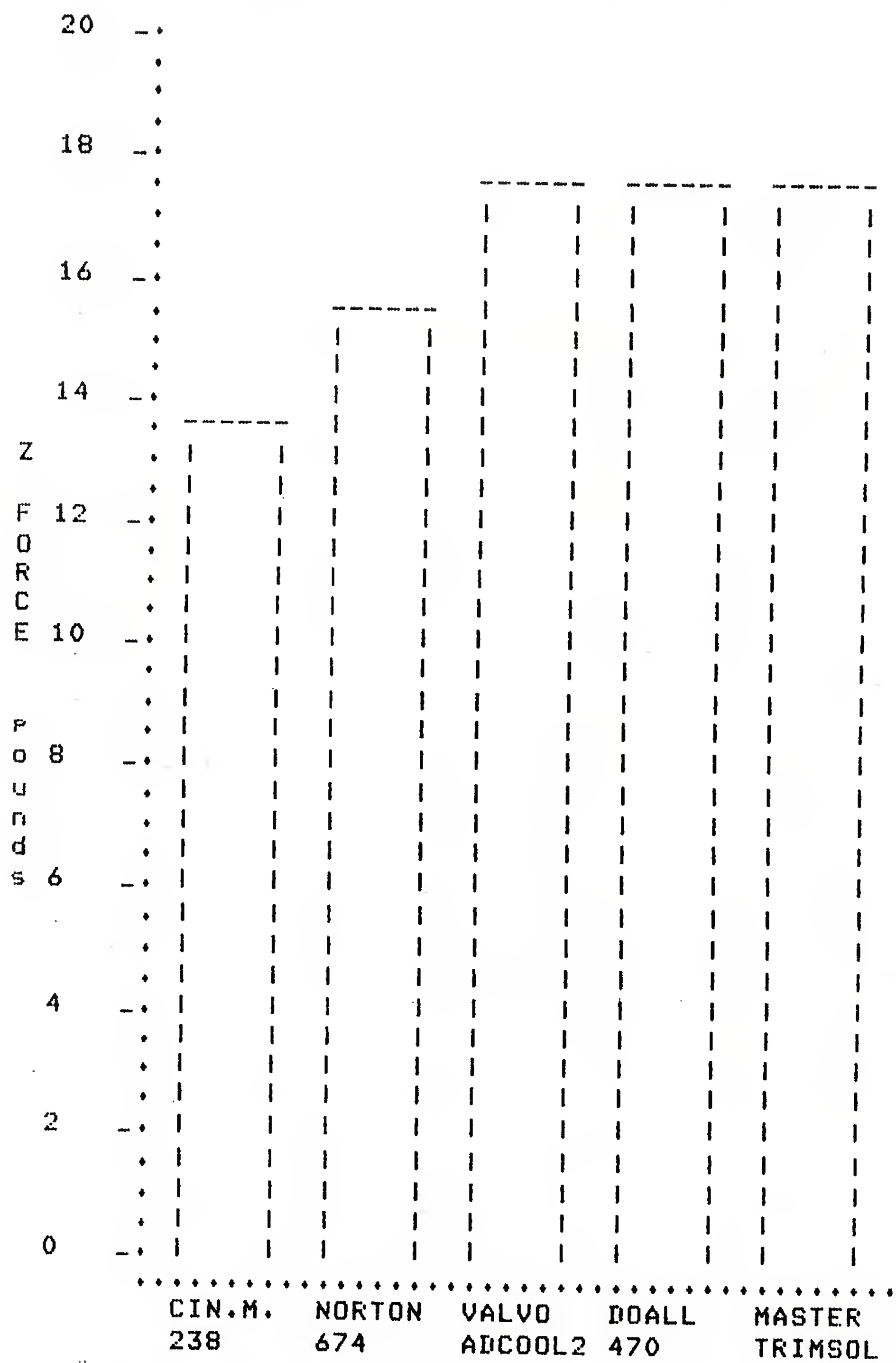


Figure 3.7-10. F(Z) Force vs Drilling Fluids Tested.

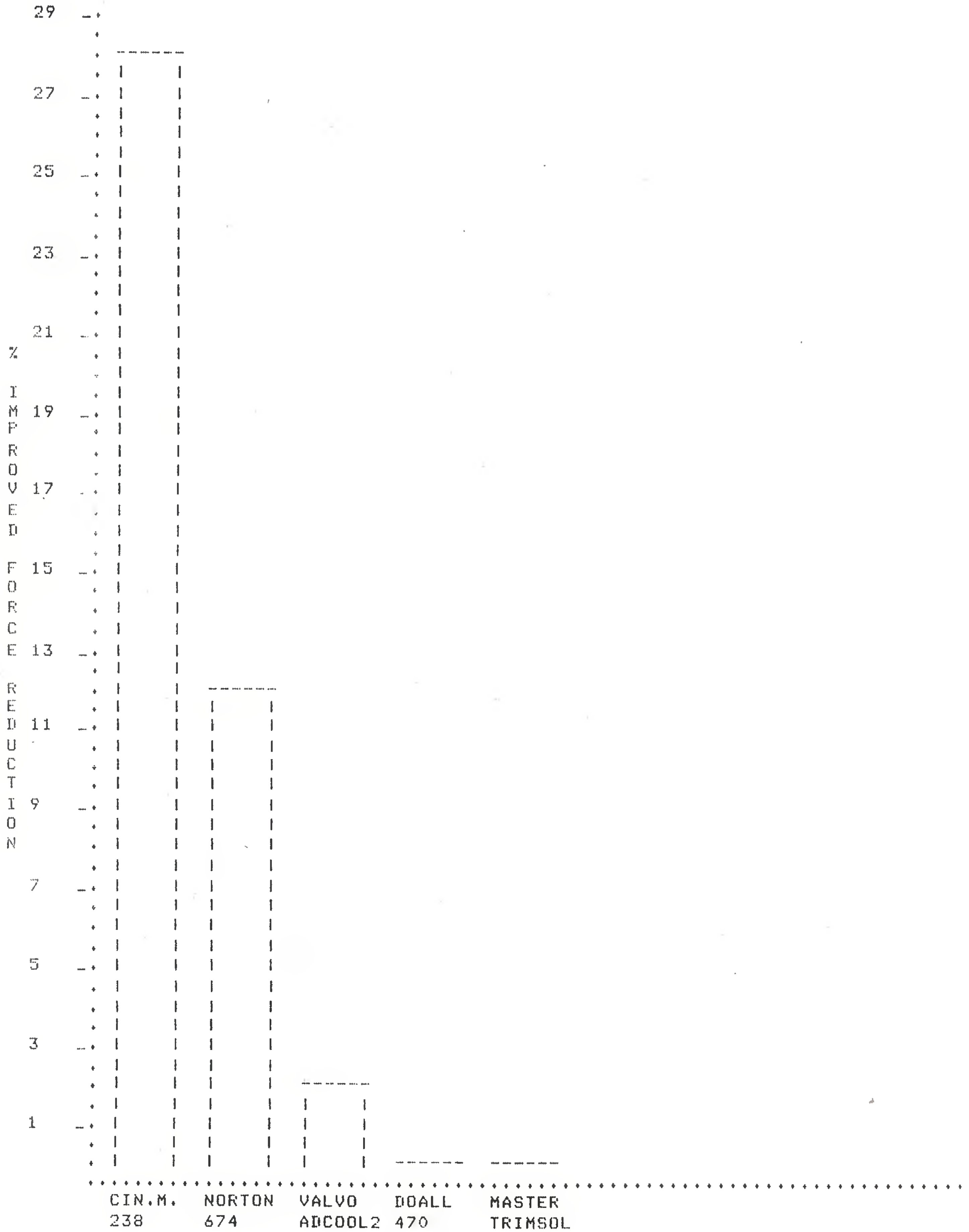


Figure 3.7-11. Percent F(Z) Force Reduction Compared to Trimsol.

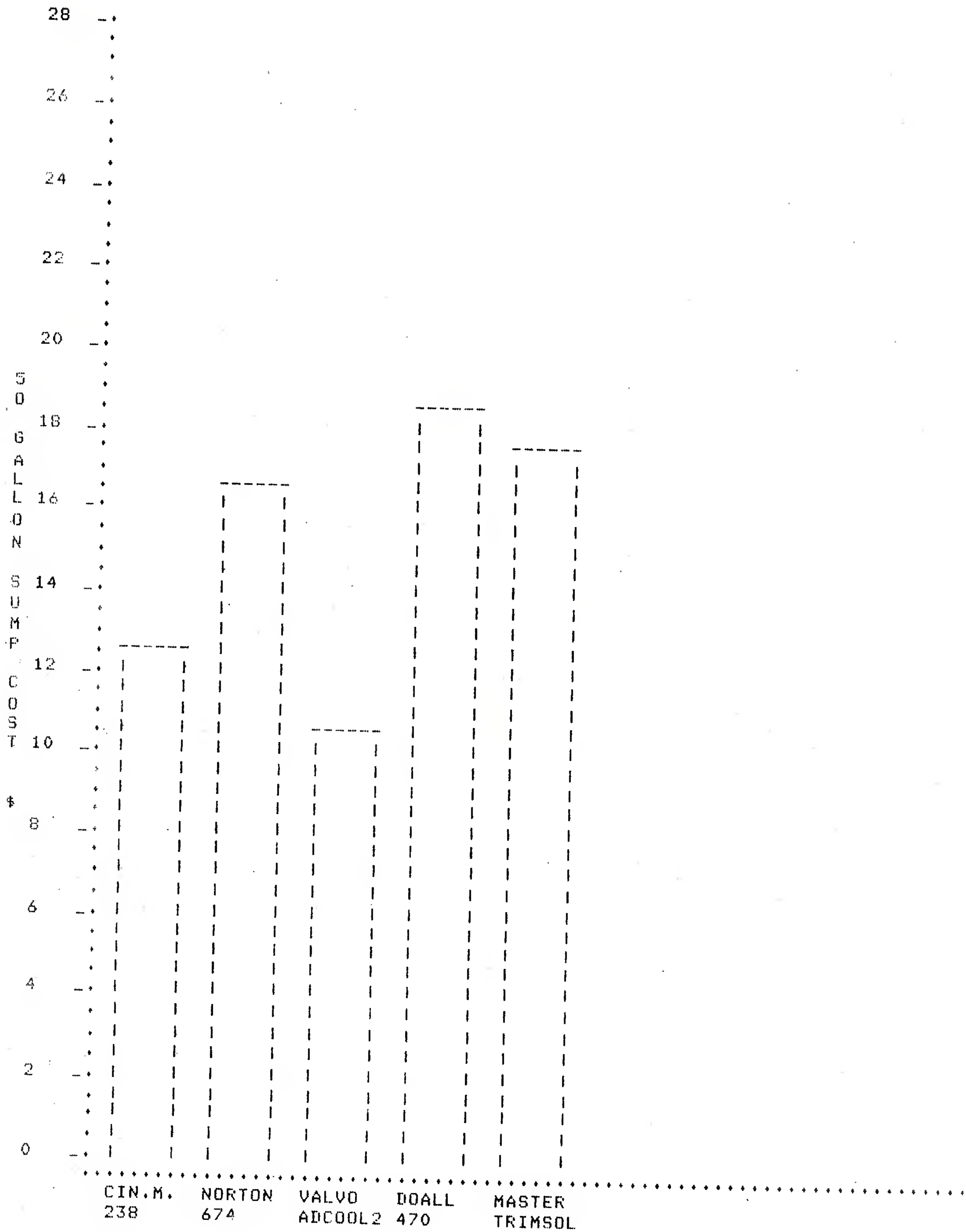


Figure 3.7-12. Price to Fill a 50 Gallon Sump vs Drilling Fluids Tested.

slower than twenty feet per minute. But the metal removal rates are high due to the fact that broach tools have many cutting edges in contact with the workpiece at one time removing unwanted material. For large quantity production of machinable alloys, usually broaching is more economical than any other type of machining operation.

The broach tool is the main part of the process. Rough, semi-finish and finished cutting teeth are combined in one tool. Many broaching tools can finish a rough surface in a single stroke. A broach tool resembles a wood rasp with its slightly tapered bar with rows of cutting teeth. Exterior broaching is when the tool is pulled or pushed across a workpiece surface or the surface may move across the tool. Internal broaching is when a broach is inserted in a starter hole in the workpiece and then pushed or pulled through it. Most irregular cross sections can be broached as long as all surfaces of the section remain parallel to the direction of the broach travel. Push broaches may be used to broach blind holes. Broach length is determined by the amount of stock to be removed and limited by the machine stroke. The length of an internal push broach should not exceed twenty-five times its diameter of the finishing teeth and a pull broach is limited by seventy-five times the diameter of the finishing teeth.

The major considerations in broaching involve speed, rise per tooth (RPT), and tooth design. Broach speed is governed by machine limitations and hardness of material. Speed is the rate at which the broach teeth pass over the workpiece. Speed is usually measured in feet per minute. Broaching feed rate is measured in rise per tooth. The rise per tooth is the difference in height between each tooth. Usually the roughing section has a greater rise per tooth than the finishing section. Tooth design is an important aspect in broaching. Unlike turning or milling, the chip does not have a place to exit and must be accommodated in the broach tooth. The tooth must also be designed in such a way to create the final form. The broach must be designed in a manner that it will maintain contact with at least two teeth at the same time.

Cutting fluid selection for broaching operations is unique because of the low cutting speeds experienced. The properties that are desired for broaching fluids are primarily lubrication oriented. Thus correctly formulated oils perform with results which are superior to the results which would be obtained with the best water soluble oil or synthetic fluids. Conventional methods to fortify a broaching oil would be the addition of chlorine, free sulfur, and combined sulfur as E.P. additives. All of these additives react with the metal on the cutting edge of the tool and on the workpiece, creating a solid film layer. This layer minimizes welding and built-up-edge which are very common modes of tool wear when broaching. The only problems resulting from fortified broach oils are operator related. Sometimes the active E.P. additives may cause dermatitis, and some operators find the sulfur odor offensive.

Cutting fluid application is very important in broaching. Fluid must make contact with the broach teeth and workpiece in order to produce an active film between the broach tooth/workpiece interface. An optimal method of fluid application in ID broaching is pumping cutting fluid through the ID under pressure.

3.8.2 RIA Broaching Survey

The broaching operation is not widely used at the Rock Island Arsenal because most of the production quantities are small lots of parts with complex geometries. There was only one broaching operation in production during the April 28, 1980 visit to the Arsenal. This operation consisted of producing the rifling internally in 50 caliber machine gun barrels. The following data are typical for this operation:

SFM:	10 ft/min
Length of Cut:	2.5 ft
Rise/Tooth:	0.0005 inch
Total Depth of Cut:	0.010 inch lands 0.050 inch grooves

This operation is a typical broach operation at RIA. After observing the operation for a period of time, it was evident that no large advances could be made in the area of cutting fluid technology. Fluid application was excellent. The cutting oil was delivered to the broach with a collet and the application pressure was 300 psi, assuring that there was sufficient fluid for the cutting operation. The broach tool was removed from the machine after each pass. As soon as tearing was evident, the broach was sent to the tool room for resharpening. During this operation the operator was in direct contact with the oil. The oil being used, Poly-Form Oil's Topaz-7/100, which utilized bromine E.P. additives. This oil did not have a disagreeable odor. Conventional sulfur and chlorine E.P. additives would have questionable odors, maybe causing operator problems. Therefore, gains made by experimentation in the area of broaching, either by fluid selection, or by application methodology would have minimal impact on overall RIA fluid application costs at this time. In the future, after major changes in closed-loop fluid delivery and reprocessing systems have been accomplished, the broaching operation will be re-examined.

3.9 Preliminary Cutting Fluid Application Matrix

In order to develop the preliminary cutting fluid application matrix, results of the cutting fluid tests were ranked for each machining process. This ranking was accomplished by comparing each fluid to the worst performing fluid in the machining category being evaluated. The fluids having the highest percentage performance increase were ranked in group number three, and those with the lowest were positioned in group one. The remaining fluids were ranked in the middle or group two. For example, in the turning tests, Van Straaten's 550-P was the lowest performing fluid with the cubic inches to .030 inch flank wear (C.30 FW) equal to 10.20 cubic inches. Trimsol has a C.30 FW of 20.41 cubic inches, which is a 100% improvement. Thus, Trimsol was positioned in group three. Norton 811 has a C.30 FW of 16.59 cubic inches, which is a 63% improvement over 550-P and it is positioned in group two. When the cutting fluid test results are clustered close together, such as in grinding, the grouping is done slightly different. The highest performing fluids are positioned in group three.

However, the lower performers are then placed in group two because they are so close to the high performers. No fluids are positioned in group one. All of the test fluid groupings are displayed in the following tables: Table 3.9-1, Turning; Table 3.9-2, Milling; Table 3.9-3, Drilling; and Table 3.9-4, Grinding.

All of the test results were then grouped into one summary, Table 3.9-5. From this table, the preliminary application matrix, it can be seen that not all of the same fluids are consistently in any one grouping for all the machining operations examined. The most consistent high performing fluid is Cincinnati Milacron's Cimfree 238, which is in group three in three out of the four machining operations examined Trimsol was ranked in group three in two out of the four processes. Overall these fluids perform similarly on most manufacturing operations. However, during some conditions one outperformed the other.

A ranking method to determine which of these two cutting fluids performed the best for all of the manufacturing processes was developed. Each fluid was given a ranking value for each manufacturing process corresponding to the group number it was positioned in. The summation of these values for all the processes becomes the fluid's overall fluid ranking. For example, Cimfree 238 has the following values which calculates its overall fluid ranking:

Manufacturing Process	Group		Fluid Rank
Milling	3		3
Turning & Boring	2		2
Drilling	3		3
Grinding	3		3
		Total	11

Overall Fluid Ranking = 11

Cimfree 238 scored eleven points on this ranking scale which ranked it the best. Trimsol scored eight points which made it a close second.

The preliminary cutting fluid application matrix was developed to specify the optimal cutting fluid for every machining process application and for all material types. Initially, this was thought to be in the form of a three-dimensional matrix. Limiting the materials to 4100 series steel eliminated the need for the third axis which simplified the matrix to a two-dimensional table which is displayed in Table 3.9-5. This table indicates that both a heavy duty fluid and a light duty fluid can have equal performance in some applications. For example, in milling DoAll's Wheelmate 470 without E.P. additives outperforms Trimsol with a chlorine additive. This demonstrates the importance of cutting fluid evaluation testing at the exact machining parameters used in production. It also demonstrates that the names such as light duty and heavy duty may be misleading in the area of cutting fluid application.

TABLE 3.9-1

TURNING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	550-P	Van Straaten	SS	C			$ 9.33
	470	DoAll	E				$18.40
	MX-5080	Economics Labs	FS			+	$26.27
2	Adcool-3	Valvoline	FS	C	S	+	$17.69
	Wheelmate 811	Norton	E	C	S		$21.00
	Wheelmate 674	Norton	SS		S		$16.50
	Cimfree 238	Cin. Milacron	FS			++	$12.50
3	Trimsol	Master Chemical	E	C			$17.25

Key:

1 = Low Performance
2 = Medium Performance
3 = High Performance

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

C = Chlorine
S = Sulfur
+ = Other

TABLE 3.9-2

MILLING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	Adcool-2	Valvoline	FS			+	$10.65
	Trimsol	Master Chemical	E	C			$17.25
2	550-P	Van Straaten	SS	C			$ 9.33
	Wheelmate 674	Norton	SS		S		$16.50
3	Cimfree 238	Cin. Milacron	FS			++	$12.50
	470	DoAll	E				$18.40

Key: 1 = Low Performance
2 = Medium Performance
3 = High Performance

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

C = Chlorine
S = Sulfur
+ = Other

TABLE 3.9-3

DRILLING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1	Trimsol	Master Chemical	E	C			$17.25
	470	DoAll	E				$18.40
	Adcool-2	Valvoline	FS			+	$10.65
2	Wheel Mate 674	Norton	SS		S		$16.50
3	Cimfree 238	Cin. Milacron	FS			+++	$12.50

Key: 1 = Low Performance
2 = Medium Performance
3 = High Performance

C = Chlorine
S = Sulfur
\+ = Other

E = Emulsion
FS = Full Synthetic
SS = Semi-synthetic

TABLE 3.9-4

GRINDING CUTTING FLUIDS GROUPED BY TEST PERFORMANCE

Group	Fluid	Manufacturer	Type	Chlorine	Sulfur	Other	50 Gal. Sump Cost
1							
2	5 Star 40	Cin. Milacron	SS				$ 9.23
	Adcool-2	Valvoline	FS			+	$10.65
3	Trimsol	Master Chemical	E	C			$17.25
	Cimfree 238	Cin. Milacron	FS			++	$12.50

Key:
1 = Low Performance
2 = Medium Performance
3 = High Performance

E = Emulsion
FS = Full Synthetic

TABLE 3.9-5

PRELIMINARY CUTTING FLUID APPLICATION MATRIX

Manufacturing Process	Group 1	Group 2	Group 3
Milling	Adcool-2, Valvoline Trimsol, Master Chemical	Wheelmate 674, Norton 550-P, Van Straaten	Cimfree 238, Cin. Milacron 470, DoAll
Turning & Boring	550-P, Van Straaten 470, DoAll MX-5080, Economics Labs	Adcool-3, Van Straaten Wheelmate 811, Norton Wheelmate 674, Norton Cimfree 238, Cin. Milacron	Trimsol, Master Chemical
Drilling	Trimsol, Master Chemical 470, DoAll Adcool-2, Valvoline	674, Norton	Cimfree 238, Cin. Milacron
Grinding		Cimcool 5 Star 40 Adcool-2, Valvoline	Cimfree 238, Cin. Milacron Trimsol, Master Chemical

Key:

Group 1 = Low Performance
Group 2 = Medium Performance
Group 3 = High Performance

4.0 CONCLUSIONS

As a result of Phase I's activities, a series of conclusions and observations have been developed which can be conveniently subdivided into the following categories: RIA manufacturing processes and materials, RIA current cutting fluid system, and fluid testing conclusions.

These categories as they apply to the overall manufacturing operation being conducted at the Rock Island Arsenal will be treated individually in the following subsections.

4.1 RIA Manufacturing Processes and Materials

A. 93% of RIA manufacturing are comprised of four processes.

93% of all the manufacturing processes at the Arsenal are turning & boring, milling, drilling and grinding. This figure is based on monthly operating hours.

B. 95% of all parts in the observed machining operations were manufactured with 4100 series steel.

During the visits to RIA, seventy-six machining operations were observed on twenty-four different parts. Over 95% of these operations were manufactured with 4100 series steel. Some bronze machining was observed being done for wear surfaces. This operation seemed to require metallurgical process optimization rather than cutting fluid improvements. An extremely minor amount of aluminum and cast iron machining is performed at RIA.

C. Chipping and cratering were the observed tool wear modes.

Seventy-five percent of the observations for turning and boring exhibited either extreme wear due to chipping or extreme wear due to cratering without evidence of flank wear or BUE effects. All of the observed carbide insert wear for milling was in the form of chipping. The turning operations observed exhibited chipping and extreme crater wear.

D. The majority of machining operations were performed at state-of-the-art parameters.

Most of the N/C turning and milling operations were performed well beyond Machinability Data Handbook type machining parameters. These operations utilized the most advanced tooling available. Also, the foremen in the conventional machining areas were well informed about the latest tooling and machining parameters and used them where possible. Their only limitations are the older equipment they must utilize.

4.2 RIA Current Cutting Fluid System

A. RIA needs some form of cutting fluid recycling system.

Currently, it is estimated that RIA is using 7,558 gallons of water-base cutting fluid and 4,556 gallons of neat oil cutting fluid a year. Also, 15,000 gallons of spent cutting fluid must be disposed of each month. This volume of new cutting fluid input and the present rate of disposal indicates that installing some form of recycling system would be an appropriate course of action.

B. Anerobic bacteria is the main reason for cutting fluid sump changes.

One result of the manufacturing survey indicated that the main reason for changing a machine's sump was that it emitted a foul odor. Not one person interviewed ever heard of anyone seeing an emulsion split. This indicates that the anerobic bacteria are causing GOOD cutting fluid not to be fully utilized and these bacteria must be controlled.

C. Cutting fluid concentrations are not at the manufacturer's recommended levels.

The data obtained to date seem to indicate improvements in manufacturing operations at Rock Island Arsenal can be achieved through modification of the present cutting fluid selection and maintenance systems. For example, the concentration level of the Master Chemical product Trimsol and the Cincinnati Milacron product Cimfree 238 have been utilized below the manufacturer's suggested concentration levels in many of the observed machine sumps. This problem may be attributed to one or a combination of the following:

1. Selecting a make-up fluid concentration that is too lean for the type of fluid loss.

There are three main types of fluid loss: chip dragout, splashout and evaporation. Evaporation is a natural process that removes water from the sump leaving the fluid concentrate which causes the remaining fluid to carry a higher cutting fluid concentration level than the initial charge. Dragout and splashout remove water and concentrate together leaving the remaining fluid at its current concentration level. Each of these conditions requires a different concentration make-up fluid to bring the sump to the desired level.

2. Utilizing an inaccurate method to mix the make-up fluid.

The make-up fluid mixture may unknowingly be mixed too lean by the Venturi type mixing system currently in operation.

3. Contaminating oils and/or bacteria may be diluting the sump concentration.

Tramp oils and bacteria have the ability to reduce the effectiveness of the cutting fluid which causes it to perform as if it lacks concentration (refer to Section 3.3.1 for clarification).

4. Utilizing an inaccurate method of measuring cutting fluid concentration.

A refractomer may not always be an accurate method to determine fluid concentration. Contaminants may become emulsified into the oil which make it appear to contain a higher than actual concentration. Also, a refractometer may not be recommended with all cutting fluids. For example, the Cincinnati Milacron Company recommends titration as the most accurate method of concentration measurement for Cimfree 238. Section 5.0 will make recommendations which have the potential to alleviate these problems.

Also, it appears that, at this point in time, centralized systems involving either small groups or a larger colony of machines in a manufacturing area make the most sense from a technological and economical aspect, and further research to develop this type of system will be continued and presented in future reports during Phase II.

4.3 Fluid Testing Conclusions

A. All of the carbide tools tested failed due to flank wear.

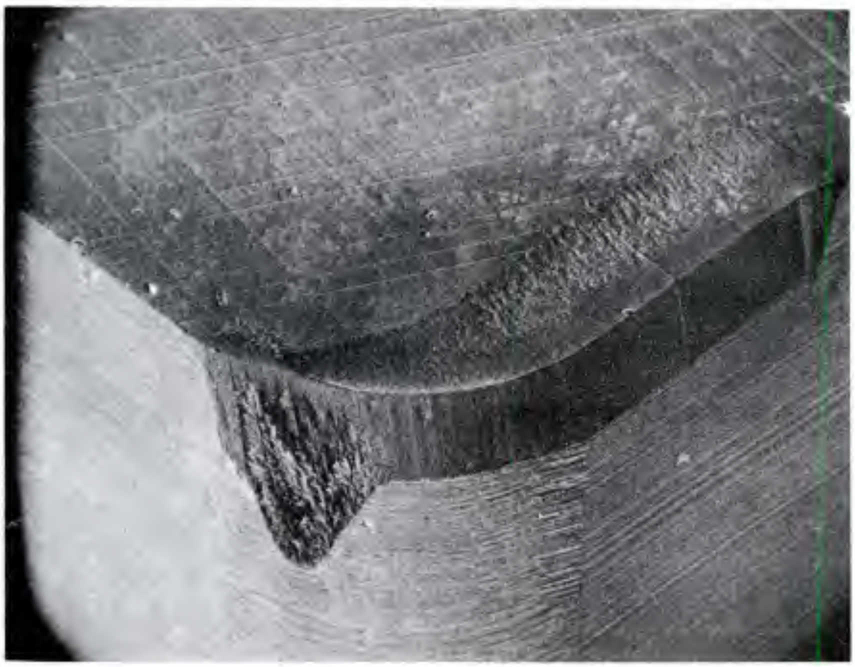
As illustrated in Figure 4.3-1, insert chipping or excessive crater wear did not cause the test tools to fail. The only source of tool failure was flank wear. In general, a good balance between crater wear and flank wear was observed. This is contrary to the observed tool wear modes experienced at RIA, which involved chipping and crater wear failures. The machining tests were all conducted at the manufacturer's recommended concentration levels. The majority of the machine sumps observed at RIA had much lower concentration levels. A logical deduction is: as the concentration of a cutting fluid decreases below its recommended level, tool wear will increase. This is based on the fact that, for the most part, the cutting fluid tests were conducted utilizing the same machining parameters and employing the same cutting fluids used at RIA.

B. Approximately 90% of all the water-soluble cutting fluid applications can be filled by one fluid.

The initial test performance results indicate Cincinnati Milacron's Cimfree 238 at a 25:1 dilution ratio ranked superior (in Group 3) in three out of the four machining categories. The only category it ranked below this was in turning, where it was rated at the highest position in Group 2. The turning test indicates that Master Chemical's Trimsol at a 19:1 dilution ratio was superior. Trimsol ranked superior (in Group 3) in turning and grinding. Master Chemical's Trimsol may also be a candidate for the one fluid to fill all water-soluble applications. Overall, these fluids perform similar on most manufacturing operations. However, during some conditions one outperforms the other.

A ranking method to determine which of the two cutting fluids performed the best for all manuacturing processes was developed. Cimfree 238 scored 11 points on this ranking scale which ranked it the best. Trimsol scored 8 points, which made it a close second. Also, economic factors would have to be considered. Currently, Trimsol

Turning Test Tool D-2; SEM @ 43X; This Test Used Master Chemical's Trimsol.



Milling Test Tool E-1; SEM @ 50X; This Test Used DOALL's Wheelmate 470.

Figure 4.3-1. Examples of SEM Examination of the Conditions of Turning and Millng Test Tools.

costs $4.75 more than Cimfree 238 to fill a fifty-gallon sump, therefore making the initial installed gallon of Cimfree 238 almost 28% lower than Trimsol. A synthetic fluid, in general, has the potential to last longer than an emulsion because bacteria and tramp oil have less of an effect on it. Also, Cimfree 238 does not contain phenols, which would make waste removal less costly. Further economic analysis must be accomplished in order to insure that an optimal cutting fluid is selected.

C. Six fluids showed signs of rusting during the fluid evaluation tests.

During the rust test, the following fluids showed signs of rusting: Cimperial 1011, Cincinnati Milacron; IRMCO 103, International Chemical Company; Wheelmate 811, Norton Company; Poly Aqua, Poly-Form Oils; 911, Wynn Oil Company; 1149, D. A. Stuart Oil Company.

D. During an intermittent cutting operation the importance of E.P. additives seems to be diminished.

During the milling tests, the cutting fluids not containing chlorine and sulfur outperformed those that did. The temperature required to cause these additives to react must not have been reached.

E. Fluid flow rates affect machining performance.

During the grinding test, a 24% increase in power and as much as a 25% increase in forces were experienced with a slight decrease in fluid flow. Also, in turning a 27% decrease in cubic inches of metal removed to .030 of an inch of flank wear was observed during a test conducted with a slight reduction in fluid flow.

F. Cutting fluid manufacturer's classifications can be misleading.

An important finding of the machining tests was that the cutting fluid manufacturer's ranking system for their cutting fluids, as shown earlier in Table 3.3-1, can be misleading. Fluids that were labeled light duty in some cases outperform those that were labeled heavy duty and vise versa. For example, during the milling operation, DoAll's 470, rated as a light duty cutting fluid, outperformed Trimsol, which was rated as heavy duty.

5.0 RECOMMENDATIONS

Based on the Phase I program findings, the following immediate and long range preliminary recommendations are presented; these initial recommendations will be further refined in Phase II and Phase III.

5.1 Immediate Recommendations

The following is a list of suggested courses of action that have the potential to reduce the Rock Island Arsenal's operating cost:

1. Mix the cutting fluids with a positive displacement pump.

Currently, the cutting fluids are mixed with a Venturi type of mixer. This method's accuracy depends on the variation of the water pressure supplied to it. This may be the major reason that many of the observed sumps have too lean of a cutting fluid mixture.

2. Bubble air into an idle machine sump.

This action will reduce the growth of an anerobic bacteria and increase the sump's life. Note: This method does not decrease the growth of aerobic bacteria but increases it. However, it was noted that the main reason for cutting fluid discard at RIA was the hydrogen sulfide (rotten egg) odor which can be attributed to a high population of anerobic bacteria. This level is in the range above 1 x 10^5-1 x 10^6 bacterium on a plate count. No mention was made by foremen or workers of an observation of an emulsion split. This is the type of reaction that could be attributed to aerobic bacteria. Therefore, aerating the cutting fluid may increase the time a cutting fluid could be used by an operator.

3. Mix the make-up cutting fluid to the dilution ratio that is required for the machine operation in question.

Various machine operations require different dilution ratios for their make-up cutting fluids. The dilution ratios depend on the amount of splashout, the amount of evaporation and/or the amount of dragout of the operation in question. For example, a turning operation is a high dragout operation which is caused by cutting fluid accumulating with the chips. This action removes the diluted cutting fluid mixture from the sump leaving the fluid at the same concentration level. The makeup should be at the recommended concentration level. Grinding produces a high degree of water evaporation from the fluid which increases the concentration of the remaining fluid. This situation calls for a make-up fluid with a lower concentration level which adds more water to the system. This causes the sump concentration level to equalize to the original recommended concentration level.

4. Monitor the concentration levels of all machine sumps.

Currently, the concentration control of the sumps may be improved if accurate methods to determine their concentration can be developed. A refractometer by itself is not an accurate method to determine the concentration of a cutting fluid after it is in use. The refractometer should be coupled with laboratory tests and used as an indicator that the cutting fluid is within a specified concentration range.

Most cutting fluid manufacturers offer a laboratory service as part of their cutting fluid cost. This service could be used to establish refractometer indices for a particular type of machine with a particular maintenance problem performing a manufacturing process. For example, a group of older lathes could have a hydraulic oil leakage problem. The refractometer index for this group of equipment will be different than if they did not leak hydraulic fluid into the cutting fluid. A refractometer reading should be taken of a sample of the fluid in the machine sump and recorded. Then the same sample should also be sent to the manufacturer's cutting fluid lab for analysis. The actual concentration level of the fluid can then be defined and a calibration factor established for the refractometer readings. Several samples must be taken to develop a refractometer range for this process. When this is determined, accurate make-up cutting fluids can be mixed for this operation. Note: If the cutting fluid ever gets out of the established refractometer range, further lab tests should be made.

Another form of cutting fluid concentration control recommended by some cutting fluid manufacturers is an analytical testing procedure called titration. this procedure measures the exact amount of a critical component of the cutting fluid. This procedure will accurately determine the concentration of the fluid.

Titration cannot be <u>easily</u> performed on all cutting fluids. Each cutting fluid manufacturer being used should be questioned as to how this procedure can best be performed in a manufacturing environment.

5.2 Long Range Recommendations

The final recommendations for a cutting fluid system at the Rock Island Arsenal will be made during Phase III of this program. However, the data collected so far at the Arsenal and interfacing with cutting fluid manufacturers have developed some basic thoughts about cutting fluid systems which will be shared in this section.

All of the fluid manufacturers contacted specified the optimal condition of their cutting fluid is when it is applied at the recommended concentration level. The fluid should not have a high bacteria count, over $1 \times 10^5 \sim 1 \times 10^6$ ppm, and should not contain excessive tramp oil contamination.

Observations have indicated that maintaining many individual sumps is an expensive and difficult method of operation. Exact concentration cannot be easily obtained with a refractometer unless monitored on a daily basis. Once tramp oil is in an individual sump, it is difficult to remove unless each individual sump has an oil skimmer or is pumped out and the fluid reprocessed and pumped back in. Having individual oil skimmers is very expensive. Pumping the fluid out and reprocessing is one possible method. However, the concept of a continuous sump is another.

A central sump system would be an integrated cutting fluid system serving a particular group of equipment. An example of the type of equipment serviced would be the N/C equipment in Shop M. The central sump would supply the cutting fluid at the desired operating pressure for a specified group of equipment. The flow of cutting fluid would be set up in such a manner that it would flow through the existing sumps using them like a holding tank. Thus, when central sump equipment failures occur, enough fluid could be kept in the machine's own sump until the equipment is repaired. The central sump's concentration could be easily monitored compared to potential errors involved in individually checking 25-50 smaller sumps. If a synthetic cutting fluid were used, a titration for a required additive could be done which would provide an accurate concentration measurement. Titrating is a chemical analysis method that is used to determine the exact amount of a chemical in a solution. This practice could be readily taught to an hourly employee. Titrations could be run to determine the exact level of biocides and cutting fluid performance additives. Only the desired additives would have to be replenished. The fluid could be reprocessed through a specially designed reprocessing system. However, most cutting fluid manufacturers recommend using medium sized decentralized reprocessing sump systems. They all refer to Murphy's Law and indicate it's better not to put all your eggs in one basket. Also, having more than one system allows for using more than one fluid or fluid concentration. The system sizes will vary depending on the type of fluid used and with what manufacturing process it is utilized. A typical reprocessing system may be viewed in Figure 5.2-1.

This concept is only a basic model at the present time. Examples made were used for illustrative purposes. Additional techniques can be added to this basic concept such as the utilization of automatic feedback control systems. Such systems could be used to test for E.P. additives, bacteria level and amount of rust inhibitor in the system and make additions to the system automatically. Such a system is in the conceptual stages at this point in time and will be further explored during the later phases of the program.

However, it appears at this point in time that a series of centralized systems of some size at particular locations seems to be the optimal solution for the Rock Island Arsenal. The questions that remain to be answered are: What size will they be? How many? Where will they be located? And what cutting fluid and concentration level will they utilize? These questions will be answered after an economic analysis is completed.

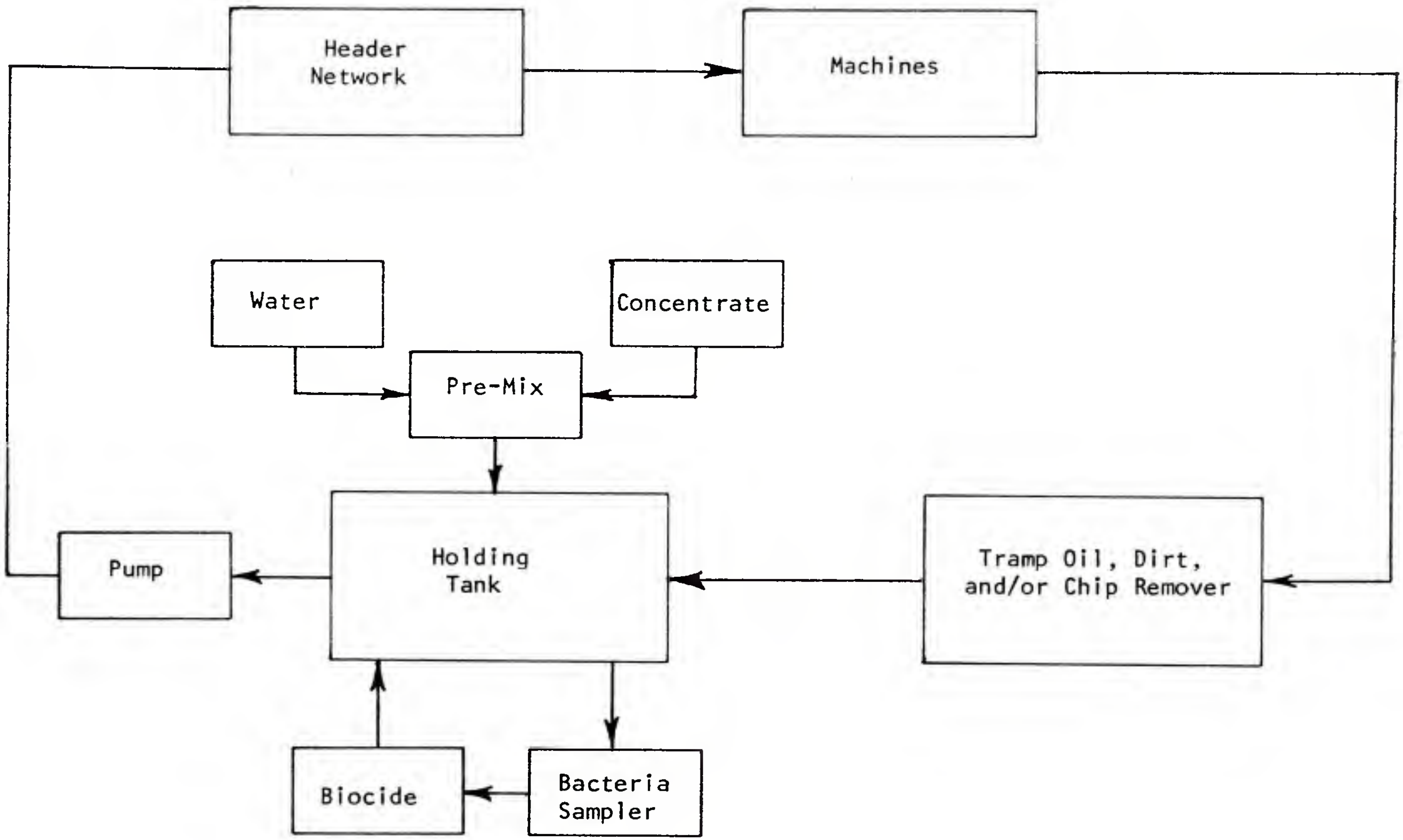


Figure 5.2-1. A Schematic of a Typical Centralized Cutting Fluid System.

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APPENDIX A

Turning Severity Index Determination Table

Weighting Factors	3	1	2	100	6				
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
Ranking Criteria	500-UP=R=3 300-499= R2 100-299= R=1	0.250-UP=R=3 0.060-0.244= R=2 0-0.059=R=1	0.026-UP= R=3 0.01-0.025= R=2 0.009=R=1	41-46=R=2 35-40=R=1 0-34=R=0		200-UP=R=3 50-199=R-2 0-49=R=1			

<u>Key:</u> SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.

MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.

Boring Severity Index Determination Table

Weighting Factors	3	1	2	100	17				
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
Ranking Criteria	250-UP=R=3 100-249= R=2 0-99=R=1	0.150-UP=R=3 0.100-0.144 =R=2 0-0.099 =R=1	0.015-UP =R=3 0.012-0.014 =R=2 0.0.013 =R=1	40-45=R=10 35-40=R=1		100-UP=R=3 50-99=R=2 0-49=R=1			

Key: SFM = Workpiece velocity, surface feet per minute.
Depth of Cut = Tool engagement normal to feed direction, inches.
Feed Rate = Tool advancement rate, inches per revolution.
OTW = Observed tool wear mode.

MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.

End Milling Severity Index Determination Table

	SFM	Feed/Tooth (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
Weighting Factors	3	1	2	200	4				
Overall Severity Index									
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0=0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		150-UP=R=3 50-149=R=2 0-49=R=1			

Key: SFM = Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.
R = Rank

Conventional Peripheral Milling Severity Index Determination Table

Weighting Factors	3	1	2	2m	2				
Overall Severity Index	SFM	Feed/Tooth (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	OTW	Operation	Part No.
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0-0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		500-UP=R=3 250-499=R=2 0-249=R=1			

Key: SFM = Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.
R = Rank

Face Milling Severity Index Determination Table

Weighting Factors	3	1	2	2m	2				
Overall Severity Index	SFM	Feed/Tooth (in.)	Feed Rate (in/rev)	Hardness	MRR	Basic Operation Severity Rank	O T W	Operation	Part No.
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
	Rank =	Rank =	Rank =	Rank =					
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0=0.0029=R=1	7-UP=R=3 3-6.9=R=3 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0		500-UP=R=3 250-499=R=2 0-249=R=1			

Key: SFM = Tool velocity, surface feet per minute.
Feed per Tooth = Amount of material each tooth removes in inches.
Feed Rate = Tool advancement rate, inches per minute.
OTW = Observed tool wear mode.
MRR = Metal removal rate, cubic inches per minute.
NHS = No hardness specified.
CH = Chipping
CR = Cratering
G = Balance between cratering and tool flank wear.
R = Rank

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